SPLINTER OF A LUCIFER MATCH

MICROSCOPICAL MANIPULATION.

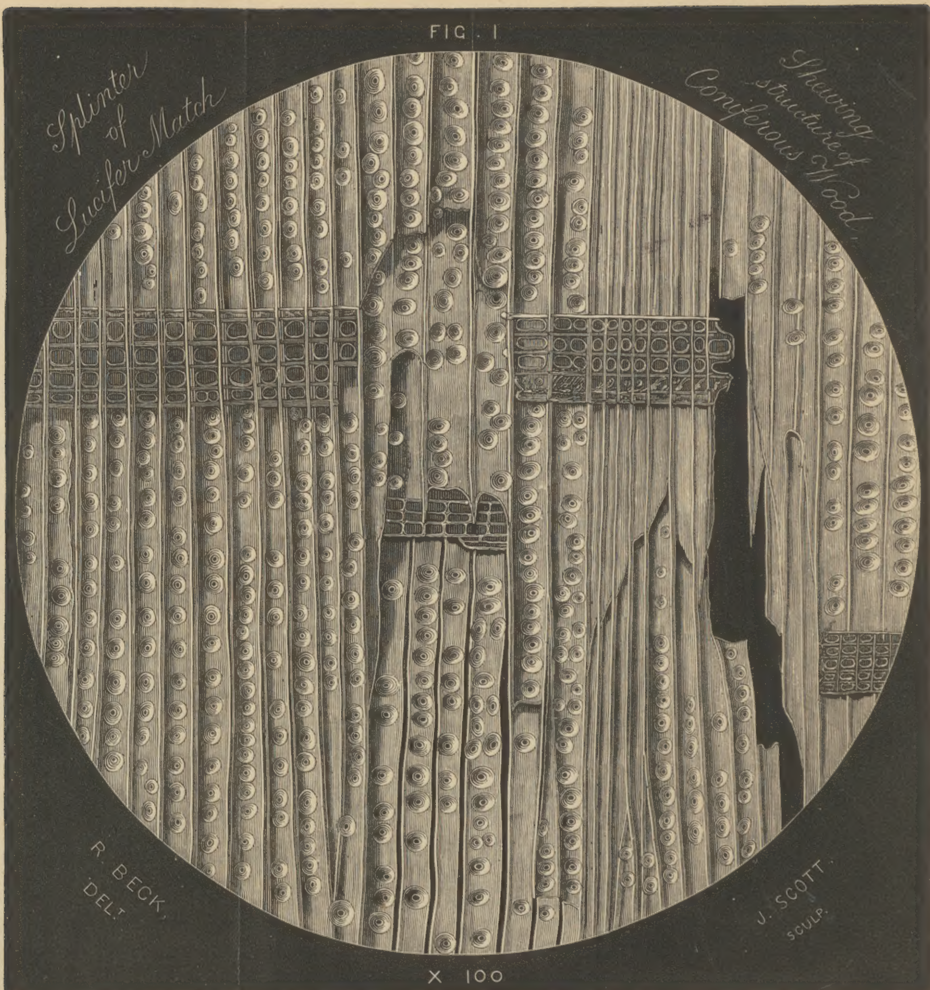
FIG. I
Splinter of Lucifer Match
Shewing structure of Coniferous Wood.
R. BECK, DELT.
J. SCOTT SCULP.
X 100

Plate I.

ON

MICROSCOPICAL MANIPULATION,

BEING THE SUBJECT-MATTER OF

A COURSE OF LECTURES

DELIVERED BEFORE THE

QUEKETT MICROSCOPICAL CLUB,

JANUARY—APRIL, 1869.

BY

W. T. SUFFOLK, F.R.M.S.

ILLUSTRATED WITH FORTY-NINE ENGRAVINGS AND SEVEN LITHOGRAPHS.

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BOY COURT, LUDGATE HILL, E.C.

To PHILIP LeNEVE FOSTER, M.A., F.R.M.S.,

PRESIDENT OF THE QUEKETT MICROSCOPICAL CLUB.

Dear Sir,

Permit me to dedicate this little volume to you, in remembrance of your kind aid in promoting the delivery of the Lectures, in 1866, which were the origin of the more extended course contained in the following pages.

And believe me,

Sir,

Yours faithfully,

W. T. SUFFOLK.

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DESCRIPTION OF THE PLATES.

PLATE 1—FRONTISPIECE.

Splinter of lucifer match after drawing by Richard Beck (pp. 169, 198).

The elongated wood cells or fibres run from top to bottom of the plate, and in some places their characteristic tapering ends are visible; they are covered with rows of peculiar pitted dots already mentioned. The bands of cellular tissue, crossing the fibres at right angles, are portions of the medullary rays. This splinter is identical with the radial section, Pl. 4, fig. 3.

PLATE 2.

Figs. 1—6. Various *Foraminiferæ* from Smyrna sponge dirt (p. 188).

Figs. 7—11. Sponge spicules (p. 187).

Figs. 12—14. Barbadoes *Polycistinæ* (fossil), (p. 195).

PLATE 3.

Figs. 1—6. Starches (p. 193).

1. Tous les mois. 2. St. Vincent arrowroot, *Maranta arundinacea*. 3. Barley. 4. Oat. 5. Maize (Brown and Polson's corn flour).

Fig. 7. Fibre of wool (p. 213).

Fig. 8. The same treated with a hot alkaline solution (p. 213).

Fig. 9. Silk fibres (p. 212).

Fig. 10. The same after treatment with hot alkali (p. 212).

This plate is a specimen of engraving on stone (p. 173), and shows the usual defects of a first attempt, principally the result of fear in cutting the surface. Engraved lines print finer than they appear on the stone. Considerable practice is required to attain excellence in this mode of lithography.

PLATE 4.

Fig. 1. Transverse section of stem of *Clematis* from nature (p. 200).
Figs. 2—6. Diagrams illustrating the structure of exogenous and endogenous stems.

Exogenous Stem—

Fig. 2. Transverse section.
Fig. 3. Radial section.
Fig. 4. Tangential section.

Endogenous Stem—

Fig. 5. Transverse section.
Fig. 6. Longitudinal section.
a, pith; *b*, fibro-vascular bundles; *c*, medullary rays *d*, bark.

PLATE 5.

Fresh water animals and plants (p. 201).

Lower figures, *Stephanoceros Eichornii*; on conferva on the right, at the top *Melicerta ringens* (*Rotiferæ*); entangled in confervæ, on the left, statoblasts or buds of *Plumatella* (*Polyzoa*).

PLATE 6.

Marine animals (p. 204).

Upper group, *Bowerbankia imbricata* (*Polyzoa*). Many of the *Polyzoa* are interesting to the microscopist on account of their transparency permitting a good view of the internal organs. The digestive organs and some of the retractor muscles are plainly seen in the figure.

Lower figures, on the left, *Campanulina acuminata* (*tenuis*), (*Hydrozoa*), from drawing by C. P. Johnson; on left, *Pedicellina Belgica?*

Plates 4, 5, and 6 are specimens of white line engraving on stone (p. 174).

PLATE 7.

Fig. 1. Fibres of wool, reflected light (p. 206).
Fig. 2. Fibres of jute, polarised light (p. 206).
Fig. 3. Fibres of silk, polarised light (p. 206).
Fig. 4. Fibres of cotton, polarised light (p. 206).
Fig. 5. Fibres of flax, polarised light (p. 206).

The swelling on the right-hand portion of fig. 5 is characteristic of the liber fibres when injured by bending or crushing.

This and Plate 2 are specimens of chalk drawing. Owing to the necessity of representing these objects on a black ground, the figures have lost much of the delicacy of detail which they possessed before the stones were "etched," the solid black ground requiring to be treated with acid to an extent injurious to the more tender lithographic chalk. The combination of large masses of ink with chalk should always be avoided when possible.

PLATE 8.

Figures illustrating interference and coalescence of waves (pp. 122, 219).

PREFACE.

THE lectures forming the principal contents of this volume were delivered at the Quekett Microscopical Club at the commencement of 1868, and were prepared for publication in the "Chemical News" from the short-hand writer's report. The lecture form has not been retained, although the chapters, with one exception,* represent almost exactly the course as delivered.

To render the subject more complete, a few notes have been added to the earlier sheets, principally relating to events which have transpired during publication; the later ones have been corrected to bring their contents as nearly as possible to the present time.

With the view of making the work more useful to those for whom it is principally intended, a

* For the sake of convenient demonstration, the subject of Chapter IV. occupied two lectures.

few practical lessons have been added; these are chiefly founded upon the demonstrations following the delivery of the original lectures. The selection of specimens for examination has been made from the most easily procured substances, rather than from those objects commonly examined by microscopists, and which have been so frequently described, that the student would probably commence his observations with some pre-conceived ideas as to structure.

The plates, which, with the exception of the frontispiece, have been executed by the author, are added principally as illustrations of the lithographic processes described in Chapter VII., and to show how far the art, in the hands of an amateur, may be rendered available for the reproduction of microscopical drawings.

The frontispiece, after a drawing by the late Richard Beck, is a fine specimen of wood engraving, and is introduced as an instance of that successful interpretation of the artist's ideas, which is, unfortunately, rare. For this, many other wood-blocks, and permission to re-produce the subject of Plate 7, the author is indebted to the kindness of Messrs. R. and J. Beck. The thanks of the author are also due to Messrs. Churchill and Sons, Messrs. Longmans and Co.,

Mr. Collins, Messrs. Winsor and Newton, and Messrs. Cotton and Johnson for drawings kindly supplied to illustrate the work.

The instruments and apparatus mentioned are chiefly those used at the Lectures, and by no means represent all procurable either in England or on the Continent. For full information on this subject the reader is referred to "Carpenter," pp. 19—238. With respect to the introduction of the names of makers, no apology is needed in the case of Messrs. Powell and Lealand, Ross, and R. and J. Beck. Mr. Collins was engaged by the Lecture Committee to supply lamps and such apparatus as was needed beyond that in possession of the Lecturer and the gentlemen who assisted at the demonstrations; and Mr. Bailey has for some time made such experimental apparatus as the author has required: this will account for the frequent mention of these opticians. In the case of other makers, omission by no means implies inferiority, as the author believes that equally good apparatus may be obtained from many of those of whom no mention has been made.

ON

MICROSCOPICAL MANIPULATION.

CHAPTER I.

THE object of the present series of chapters is to place my own practice before beginners in microscopical science, for although there are a vast number of existing works on the microscope, many of them are of a popular nature and addressed to those who seek in the microscope a means of recreation rather than of scientific research. My wish is to supply simple and practical directions to aid the student, giving very much in detail such processes as are but little mentioned in books, and which are more usually learned by seeing the instrument in the hands of an experienced person; but as this is an advantage not accessible to every one, it would seem that there is still a want, which it is my hope this and succeeding chapters will help to supply, and prepare the student to consult with profit more elaborate treatises.

I have thought proper, therefore, to devote this chapter to the consideration of the instrument we have

to work with. No workman is any the worse for a knowledge of the contents of his tool-chest; in fact, he will be far better qualified for making use of the appliances he possesses by knowing their construction.

Microscopes vary much in their details of construction, each maker having an instrument for which he claims its own especial merit. For convenience sake, the general plan of structure may be described as consisting of a tube containing the optical portion, capable of a sufficient range of motion to and from a support for the object to be examined, known as the stage, beneath which is placed a mirror, provided with the necessary adjustments for reflecting light upwards through the aperture in the stage.

The plans employed for supporting the tube containing the lenses, or "body," are two in number; in one, that adopted by Messrs. Beck and a few other makers, the body is supported by the greater part of its length, and runs in groove of peculiar form, which effectually prevents the detrimental movement known as "twist." In the other mode, the one used by Messrs. Ross, Powell and Leland, and the majority of opticians, the body is attached to the extremity of the cross-arm, the rack work moving up and down in a tube attached to the trunnions which carry the instrument between the two uprights connected with its base. This last plan of construction involves the use of a greater weight of metal and a more careful disposition of it to secure stability than where the body is supported in the former manner, but when

skilfully made there is no practical objection to its employment.

Dr. Carpenter speaks highly of the first mode, which is also approved of by Dr. Bowerbank : my experience is decidedly in its favour, my own instrument so constructed having been exposed to more than ten years' severe wear, and having had no substantial repairs during that period.

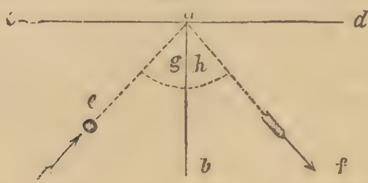
The part of the microscope I wish to direct attention to in the first instance, is the body and its contents. A combination of lenses, called the object glass, is screwed to the bottom of the tube, and another called the eye-piece, is placed at the top. For the sake of simplicity, the binocular arrangement will be for the present omitted, the instrument being supposed to have but a single body. In order that the use of the glasses contained in this tube may be understood, I must direct attention in the first place to some of the properties of light.

A *ray* of light, which is a very arbitrary term, may be considered, for the present purpose, as a small cylinder of light—a thing which has no real existence in nature, but will serve well for the purpose of demonstration. It is very much what the line is in mathematics.

Should this ray of light fall upon a polished surface which is not capable of allowing it to go through, or, in other words, an opaque polished surface like a bright plate of metal, *c*, *d* (Fig. 1), if the ray of light, *b*, *a*, falls upon that surface perpendicularly, it will be sent back by the same course

through which it came down. On the contrary, should the ray of light *e*, *a*, fall obliquely, it will be reflected at an angle, *b*, *a*, *f*, equal to that *e*, *a*, *b*, at which it fell upon the reflecting medium. This angle of incidence, *e*, *a*, *b*, will be equal to the angle of reflection, *b*, *a*, *f*. Now this principle is made use of in our commonest means of illumination,—the mirror under the stage by which the light from a lamp or other source of light at one side or in front of the microscope, or in any other convenient place, is directed through the axis of the instrument. In

FIG. 1.



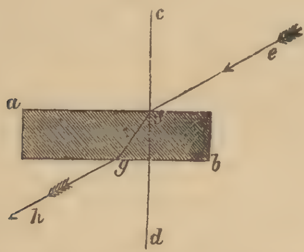
the subsequent chapters I shall say more about the application of the reflective principle. This is the only instance to be noticed at present.

Now, supposing that the ray of light falls upon a transparent material (a plate of glass, for example, a substance more dense than air), should the ray, *c*, *f*, fall upon this plate of glass, *a*, *b* (Fig. 2), perpendicularly, it passes straight through it without any alteration taking place; but should the ray of light, *e*, *f*, fall obliquely, it will no longer pass through in the same direction, but will be bent towards the perpendicular, *c*, *d*, in a greater or less degree according to the density

of the medium, as at *f*, *g*, and is bent again upon its emergence into the rarer medium at *g*, towards *h*.

The amount of "refraction," as this bending is called, would be much less with water than it would

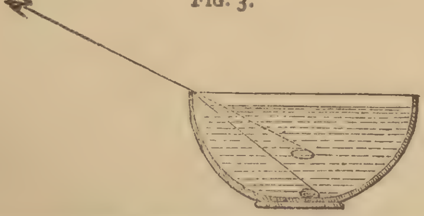
FIG. 2.



be with glass, and it would be greatest of all in the diamond, other substances refracting in intermediate degrees.

The effect of refraction is familiarly illustrated by the well-known phenomenon of objects immersed in water appearing to be nearer the surface than they

FIG. 3.



really are, a pool appearing to be only three or four feet deep, when in reality it is nearer six or eight. This may be readily demonstrated by placing a stick or

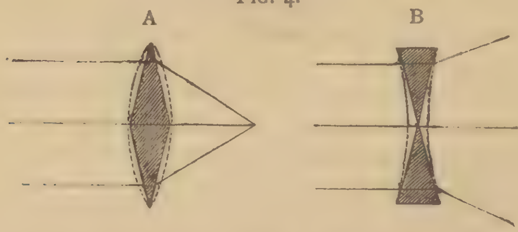
other object in a basin of water (Fig. 3); the stick will appear bent where it enters the water; a coin or other object will appear to be at a much less depth than it actually is.

It is owing to refraction that we are able to make use of lenses, which give us the power of bending rays of light and turning them about in any way that may be required.

Lenses are circular pieces of glass or other transparent material capable of refracting light, and having curved surfaces, either convex or concave.

The action of a lens upon a ray of light will be best understood by reference to Fig 4. For the sake of

FIG. 4.



simplicity the dotted curved lines representing the section of the lenses may be considered as straight lines, as shown in the diagram.

It has been shown (Fig 2) that when a ray falls obliquely it is refracted, but that when it falls at right angles with the refracting medium it suffers no refraction. The central ray in both A and B passes straight through without refraction; in A the inclination of the surfaces is such that the rays passing

above and below the centre line converge at a point called the focus. The lens, B, being thickest at the margin, the effect is just the reverse; the rays are dispersed, and do not come to a focus but diverge, as if they proceeded from a point on the opposite side of the lens, called the virtual focus. These concave lenses do not magnify, but are used in microscopes and other optical instruments, for purposes to be hereafter mentioned: the most familiar instances to be cited of their use are as the eye-glass of an opera-glass or Galilean telescope, and as spectacles for short-sighted persons.

Lenses may be made with one side worked to a plane surface and the other either convex or concave, such lenses are known as plano-convex and plano-concave lenses; their respective powers are about half those of lenses of similar and double curvatures. There are also lenses convex on one surface, and concave on the other; these are called meniscus lenses; the curves may be so proportioned that they have either the power of convex or concave lenses, according as they are thickest in the middle or at the edge; they have, moreover, some properties peculiar to themselves which are turned to good account by skilful opticians.

The formation of images is one of the most valuable properties of convex lenses, and one taken advantage of in the construction of optical instruments. If a convex lens is held at the distance of its focal length in front of a sheet of paper or other white surface, an inverted picture more or less distinct will be

seen of objects that may be before it, such as a window or candle flame. This is illustrated by the diagram Fig. 5, representing a candle flame on the left hand, from the apex of which two rays diverge, the lower

FIG. 5.

one reaching the lower edge of the lens and the upper one its centre. Rays proceed from each point of the flame to every part of the surface of the lens, but, for the sake of clearness, only two are here represented. After passing through the lens they converge; the same takes place with the rays proceeding from the lower part of the flame, which also pass through the lens. The result is the formation of an inverted image, the size of which and its distance from the lens are dependent upon the distance of the object and the focal length of the lens.

The greater the distance of the object, or "anterior focus," the shorter will be the distance of the image, or "posterior focus." The commonest example may be taken from the operations of the photographer, who, if he wants to take a small portrait, will place the sitter at a great distance from the camera, if, on the contrary, he desires a large figure, he will bring his model nearer; in the former case the posterior focus of the camera will be shorter than in the latter,

which is shown by the camera requiring to be lengthened when the model is brought near to it.

Besides the use of lenses to form images, they are also employed as magnifiers, and constitute the simplest form of microscope. Most naturalists and microscopists are provided with some little contrivance of this kind either attached to the watch chain or carried in the pocket,—either one or more lenses suitably mounted, or the Stanhope lens. In all these simple microscopes no image is formed, so that the principle upon which a magnified view is obtained is different. The idea of the magnitude of an object is formed entirely by the space which it occupies upon the retina of the eye. It is quite irrespective of its actual size; or, to express it in mathematical language, an object is large or small in proportion as it subtends a great or small angle with respect to the eye.

The eye has a certain power of adjusting itself to view objects at different distances, but there is a limit to the distance of distinct vision. It varies from five to ten inches in different persons. An object cannot be distinctly seen nearer than either one or other of these distances, or some intermediate point. Now optical science supplies a means of overcoming this difficulty. An object apparently enlarged by being brought nearer to the eye, becomes indistinct, because the pencils of rays proceeding from it diverge too much to be brought to a focus on the retina by the lens of the eye.

The optical instrument most closely resembling the eye is the camera obscura. When the rack is

run out to its full extent and the body is drawn out as far as it will go, and the object is still too near to be focussed distinctly, the position is precisely that of the eye with an object too close to it for distinct vision.

The remedy with the camera, supposing that no more focussing space could be obtained, would be to shorten the focus of the lens; that is, use one of greater refractive power. The same thing must be done in the case of indistinct vision, by interposing a convex lens, and so increasing the convergent power of the lens of the eye; the object, hitherto too near the eye, *a*, *b*, is thus rendered visible and clearly defined, but with this remarkable difference, that it appears not to be the image of the object placed near the eye, but of a larger object, A, B, at the distance of distinct vision. No crossing of the rays takes place, and consequently the image is not inverted.

Fig. 6.

The hand magnifier is an extremely useful instrument, but many persons find great trouble in using it to

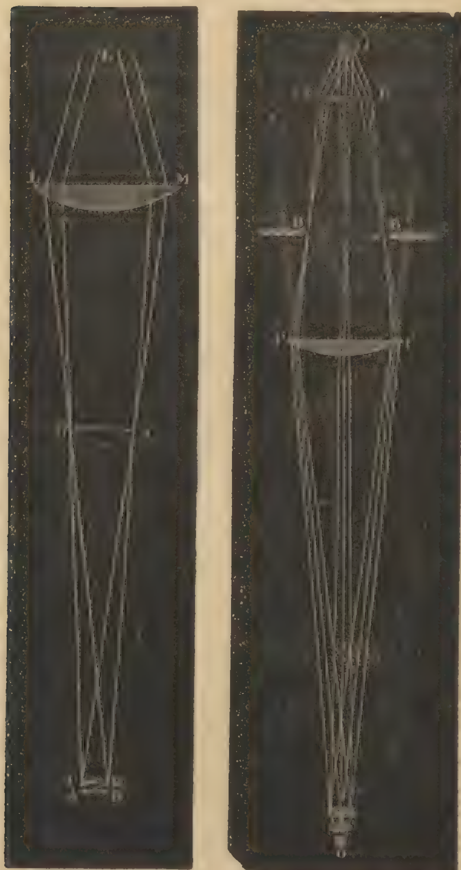
advantage, especially when it is of short focus and high power. A trifling hint about its use may be of value.

Hold the object in the left hand, either in the fingers or with forceps, and, placing the left hand against the right which is holding the lens, look through the magnifier and adjust the focus. The view is usually most distinct when the eye is in one focus of the lens and the object in the other; the two hands being held in contact move together and prevent that tremor which would be apparent, especially with high powers, if the hands were kept apart, and which unsteadiness prevents any accurate view of the object being obtained. Single lenses, when their diameter exceeds that of the pupil, possess the property of bringing light to the eye and rendering the object clearer than it would be without such assistance. This may be proved by looking at print or other suitable object in a bad light, and noticing how much the magnifier aids by its light-collecting power.

Single lenses are mounted on stands of various kinds, and then they become what are called single or simple microscopes. The older observers had no other instruments. These may consist of many lenses, while the compound microscope may be made with as few as two; but then they act upon the principle that no image is formed, but the object is rendered visible at a shorter distance than it could be without optical aid. Single microscopes are still in use for dissection and other purposes where only

Fig. 7.

A B



a low power is required. And various contrivances have been adopted by which both eyes may be used and much fatigue saved in protracted operations.

The compound microscope differs from the simple instrument just mentioned in an image being formed and again magnified by being viewed with another lens or eye-piece (Fig. 7, A).

From what has been said before respecting the formation of images, it is evident if a lens of short focus is used and an object placed before it, the image will be formed at a great distance behind it and be much enlarged; if instead of viewing this image directly, as in the camera obscura, it is viewed with a suitable lens, L, M, another enlargement takes place. Such an instrument might be constructed with only two lenses, as in the diagram Fig. 7, A, but a microscope so made would of course be a very imperfect instrument; indeed it would in almost every point be inferior in its performance to that of a simple lens, principally because the eye lens magnifies all the imperfections of the image formed by the small lens or object-glass. These imperfections are chiefly caused by the spherical and chromatic aberrations of the object-glass, and also in some degree by those of the eye-piece.

Theoretically, convex lenses bring parallel rays to a point called the focus, at a distance from the lens dependent upon the radii of their curved sides. Practically, this is not the case; the rays passing through the marginal portion of the lens come to a focus at a shorter distance from it than those which

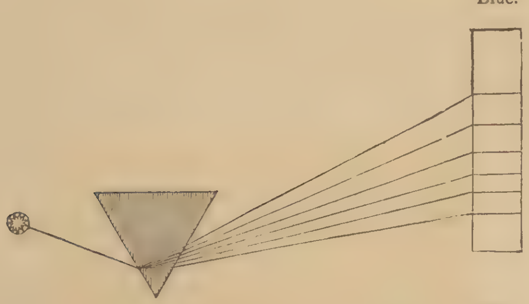
pass through or near its centre (Fig. 8). Those passing through intermediate portions converge to some part between these two points; the result is that indistinct images are formed at various points between F and *f*, Fig. 8, no well-defined figure being seen anywhere. Could lenses be made having an hyperbolic or elliptic section, the spherical aberration would be corrected, but the difficulties of making lenses of such figures are so great as to be considered

FIG. 8.

impossible in practice. Spherical aberration may be lessened by reducing the aperture of the lens, by cutting off the marginal portion by means of stops or diaphragms; but any great use of this means causes a loss of light very detrimental to the performance of the instrument. Advantage may also be taken of the position in which the lens is placed and also of its figure; the spherical aberration of some lenses, such as plano-convex and meniscus, is much affected by the way they are placed, being much greater in one position than other. Much may be done by placing the glasses in their most favourable position and using suitable curves: as a striking example, take

to pieces a photographic lens and observe the curious forms adopted in its construction. The details of these corrections are rather a matter for the practical optician, and are unsuitable for an elementary treatise on the microscope.

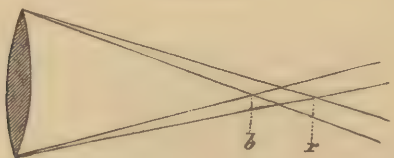
FIG. 9.



Chromatic aberration is caused by the unequal refraction of the constituents of a ray of light. If a ray be bent by passing through a glass prism, instead of the ray appearing on the other side as white light it will be decomposed, owing to the unequal capability of bending which the rays possess; the red ray is bent least, the yellow more, and the blue and violet most of all (Fig 9). This also takes place when light is caused to pass through a lens (Fig. 10). The blue ray being the most refrangible comes to a focus nearest to the lens at *b*; the red ray being the least refrangible will not converge until it reaches *r*; the yellow, green, &c., rays come to a focus at intermediate points, so that a series of images surrounded by fringes of their

respective colours would be formed at various points between b and r, such coloured margins rendering the definition extremely defective. Chromatic aberration may be lessened by the use of stops, cutting off the marginal portion of the lens, but at the sacrifice of a great quantity of light and the impairing of some of the most valuable qualities of the glass for microscopic purposes. Fortunately, a means has been

FIG. 10.



found of almost entirely correcting chromatic aberration. Different kinds of glass vary not only in their refractive power but also in the degree in which they disperse the coloured rays, and, by combining lenses of suitable forms and materials, the error of one lens is so neutralised by the opposite error of the other that the combination as a whole is nearly free from the production of colour, or becomes, as it is termed, achromatic. For the practical application of this valuable fact, we are indebted to the elder Dollond, who constructed telescopes on this principle towards the end of the last century. The object glass of the microscope was not improved until many years afterwards.

Owing to the very divergent condition of the rays proceeding from a minute object placed near the lens

of a microscope, the construction of an achromatic object-glass is much more complex than the combination employed in other optical instruments. High powers contain as many as three combinations of compound lenses placed behind each other, the careful adaptation of which requires the greatest skill on the part of the optician, and necessarily causes objectives of large aperture and great perfection to be very costly. A valuable series of papers by Mr. F. H. Wenham on the construction of object-glasses for microscopes will be found in the *Monthly Microscopical Journal*, vol. I., pp. 111, &c.

So perfectly was the correction of the chromatic and spherical aberrations effected, that it was found that even the covering of the object to be viewed with a thin plate of glass or mica rendered the image sensibly indistinct: fortunately the defect was no sooner discovered than the late Andrew Ross applied a simple remedy; some alteration was made in the disposition of the correcting media, and the front combination allowed a small range of motion backwards and forwards, which is usually regulated by a graduated collar, the use of which it will be well to explain, as, although it is to be found in most works on the microscope, it seems to be generally overlooked. Makers differ a little in the details of their arrangement for this correction, but there will always be found some mark indicating when the object-glass is corrected, for viewing an uncovered object. Focus carefully for distinct vision, with the glass so arranged, and then, taking hold of the collar, turn it round until

a view is obtained of dust that may be resting on the upper surface of the cover of the slide ; if the object is now focussed by the use of the fine adjustment, the correction for the thickness of the cover glass will be found to be very perfectly made, and as the collar is usually graduated, the number may be noted on the slide for future use, as it is constant with the same object and eye-piece, and also for the same thickness of cover-glass.

The eye-piece usually employed in the microscope in combination with achromatic object-glasses is that invented by Huyghens, a Dutch astronomer (Fig. 7, B), and consists of two plano-convex lenses (E E and F F), with their plane sides towards the eye ; this eye-piece, although not achromatic, when used with object-glasses slightly "over-corrected," renders the instrument achromatic as a whole. The optical principles involved are far too complicated to find a place in the present chapter.

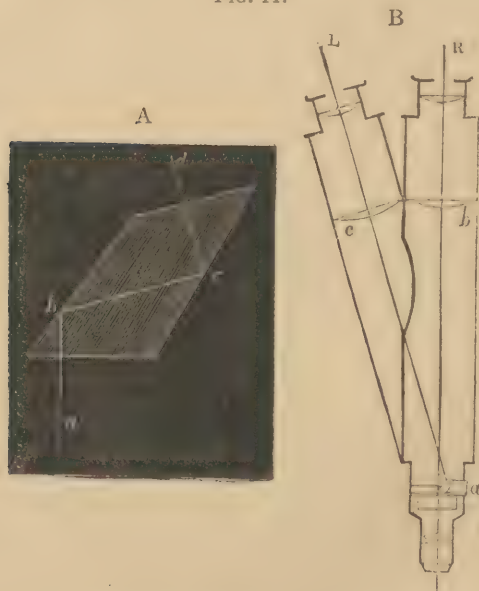
The power of the instrument may be greatly varied by using a series of eye-pieces of different power, and if the corrections of the object-glass are perfect, and its angular aperture sufficient to admit a large amount of light, great advantage may be derived from the use of a short or "deep" eye-piece ; but as the magnifying power of the eye-piece exaggerates every defect of the image, it is only with good object-glasses that this means of increasing the power is available. A very deep eye-piece is of value in testing the quality of an objective, as it causes defects which may not be apparent with lower powers to become very marked.

The power of the instrument is greatly influenced by the length of the tube or body, and were it not for the inconvenience of excessive length, this would probably be the least objectionable way of increasing the magnifying power; but a very long tube renders manipulation difficult, on account of its removing the hands to an uncomfortable distance from the stage and illuminating apparatus. Most microscopes have a sliding tube in the body known as the draw-tube, by which the length can be increased to the extent of four or six inches at pleasure.

A description of the compound achromatic microscope can, at the present time, hardly be considered complete without some mention of binocular instruments. The binocular principle had been applied to opera glasses with great success for many years. More recently the invention of the stereoscope and its great popularity drew increased attention to the subject of binocular vision, but until a few years ago no attempt seems to have been made to adapt the principle to microscopes. Owing to the short focal length of microscopical objectives, the use of two convergent instruments would of course be impracticable; the only resource was to divide the pencil proceeding from the object-glass and convey half to each eye. The earlier attempts resulted in the production of pseudoscopic instruments; that is, the relative positions of the object viewed were reversed, projections being represented by depressions and the contrary. This was found to be caused by the rays of light being conveyed to the wrong eyes, the right

side of the image entering the right eye, and the left the left eye, the effect being that of a wrongly mounted stereoscopic picture. It was found necessary that the right-hand image should be conveyed to the left eye, and *vice versa*, to produce a stereoscopic

FIG. 11.



effect; this was accomplished by M. Nachet of Paris, and Mr. Wenham by different methods, each having their respective merits. As Mr. Wenham's is most in use in this country, I will briefly describe it. A four-sided prism of peculiar form (Fig. 11, A) is placed

in the body of the microscope, just behind the posterior combination of the object-glass (Fig. 11, B, *a*), which, when in position, it half covers. An additional body, L, is joined at a slight inclination to the left-hand side of the instrument, and the two bodies are furnished at their upper extremities with draw-tubes, which supply the means of making an adjustment for the varying distance between the eyes of different persons. The image formed by the left-hand half of the objective passes up the straight tube to the right eye without being in any way interfered with by the prism; the right-hand image falls on the prism, is twice reflected, and passes into the left-hand inclined tube, and in this simple manner the crossing of the images from the two sides of the objective is effected, only one-half of the pencil suffering any reflection at all, besides giving the great advantage of instantly converting the instrument into a monocular by simply withdrawing the prism. It is only due to Mr. Wenham to mention that he has, with most praiseworthy liberality, granted free and unconditional use of his valuable invention to the public.

The binocular arrangement of Mr. Wenham cannot be used with advantage with objectives of less than half an inch focal length, but several arrangements have been constructed by which both eyes can be employed in high power observations, the most noteworthy of which has been brought forward by Messrs. Powell and Lealand. This instrument does not produce any stereoscopic effect, but nevertheless greatly diminishes the fatigue of

protracted observations. A still more perfect adaptation has been constructed by Mr. Wenham, in which the light in each tube has been more nearly equalised than in preceding instruments.

The stereoscopic binocular offers many advantages over the monocular instrument, not the least of which is the saving of the fatigue to the eyes from which most persons suffer in a greater or less degree when using one eye for observation. Did the binocular arrangement do no more than this it would be a great boon, but it has the valuable property of enabling the observer readily to estimate the amount of elevation and depression of the surface he is viewing, and accurately to determine the relative position as to depth of the various parts of the tissue under observation. The discoveries which we owe to this improvement of the microscope have been numerous and valuable; among the earliest were some interesting observations on the circulating system of the tadpole, by Mr. W. U. Whitney (*Trans. Micros. Soc. Lond.*, vol., x., 1862, p. 1; and vol. xv., p. 43). Several also by the late Richard Beck; among them the re-discovery of the aperture in the fang of the spider figured by Leeuwenhoek (Hoole's English Translation, vol. 1., Pl. 2, fig. 19) (*Science Gossip*, 1866, p. 201).

By a slight variation of the form of the prism, Mr. Crouch has succeeded in constructing a microscope which can, by merely shifting the position of the prism, become stereoscopic or pseudoscopic at pleasure. This modification of the binocular will probably be of

value in confirming certain doubtful points of structure, by giving a reversal of the parts in relief.

Further particulars respecting the construction of the microscope and the optical principles involved will be found in the "Microscope and its Revelations," by Dr. Carpenter, and "Manual of Natural Philosophy" by Mr. Charles Brooke.

The microscope being a costly instrument, it is necessary that great care should be taken to preserve it from injury. When out of use it should be returned to its case, or may be conveniently covered with a large shade or bell-glass. The eye-pieces should be carefully cleaned, as dust upon them becomes very apparent. The object-glasses, if kept in their boxes when out of use, will seldom require much cleaning; dust on the object-glass only causes a slight loss of light, but does not make itself visible. The best material for cleaning lenses is a piece of very soft wash-leather from which all dust has been beaten out; it should be kept in a large pill-box when out of use to preserve it from dust and grit, and should on no account be used for any other purpose, such as cleaning the brass-work of the instrument. Should the object-glasses require anything beyond mere dusting, they should be placed in the maker's hands, as they are liable to injury if taken to pieces by inexperienced persons.

The sources of light for the purposes of observation will need a few remarks. When it can be procured, daylight is in every respect to be preferred to artificial sources of illumination, as by it alone can colours be perfectly seen and distinguished, and day-

light observations are far less fatiguing than those made by lamp-light. Direct sunlight should be avoided, and, if possible, the light taken from a white cloud. But in towns, as the sky is seldom visible, and, moreover, few persons have much time to observe by daylight, it becomes important to seek for a good source of artificial light.

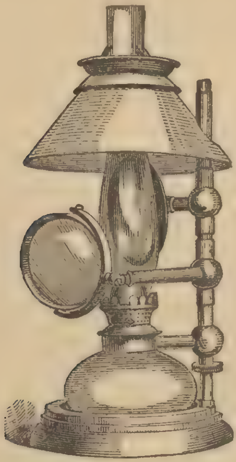
Gas has been used by many microscopists; it has the disadvantage of giving out a large amount of heat, and the quality of the light is inferior to that obtained from most other sources; its sole advantage is its convenience, as it is always ready for use, and requires no trimming, as is the case with lamps.

Well constructed lamps burning colza oil give a light of good and pure quality, although not as intense as those presently to be described. The best oil lamp I have used was obtained from Mr. Pillischer, and was only abandoned for the very intense camphine lamp. Oil-lamps require great care in trimming and cleaning, otherwise they will not burn well.

The mineral oils (paraffin, belmontine, &c.), when of good quality, and consumed in properly constructed lamps, are among the best of the microscopist's means of illumination. The quality of the light is good, and there is very little trouble required in keeping the lamp in good working order. The glasses, as in all lamps, should be kept clean, otherwise much light is lost, and to obtain the best possible effect the lamp should be trimmed each time of using, although it will burn very well two or three times without any attention.

The best way of obtaining a good oil is to try small samples from various shops, and when a good one is found keep to its use. The burner exercises a very great influence upon the light, so great that in a series from various makers it would hardly be supposed that they were burning the same oil. The burners of American make supplied by Mr. Collins with

FIG. 12.



the Bockett microscope lamps (Fig. 12), are some of the best that I have met with. This lamp has recently been improved by the adaptation of a metal chimney which is not liable to breakage, and also has the advantage of protecting the eyes of the observer from the light.

The best light of all for those who do not mind

the slight amount of trouble attending its use is obtained from the combustion of camphine or highly rectified spirits of turpentine in a small lamp, especially constructed for the purpose by Mr. W. Young. The light is much whiter and more intense than that of any other lamp; owing to this quality the flame can be very much reduced in size, and most of the heat of a large lamp avoided, a matter of importance where the lamp is often placed near and below the face of the observer.

Camphine, when not used quickly, should be kept in small bottles, filled up to the neck, and closely corked, and kept in a cool place—a wine-cellar answers admirably. For the small consumption of the microscope lamp the bottles should not exceed four or five ounces, as the spirit rapidly deteriorates by exposure to the air both from evaporation and the absorption of oxygen, which renders it liable to clog the wick and reduces its illuminating power. The wick should be cut very exactly to a level, far more carefully than would be required for oil or paraffin, the least uneven point rendering the lamp liable to smoke. No more camphine than is likely to be consumed should be placed in the lamp; if there is more than is needed it should be allowed to burn itself out, or be thrown away, and the wick allowed to burn dry, otherwise the lamp is liable to become clogged, and burn badly. Should any part of the lamp become incrusted with a resinous deposit, it must be cleaned with methylated spirit; care should be taken that none of the air passages are obstructed.

Although these precautions may seem troublesome, they really are not so to persons willing to acquire the habits of neatness so necessary to those who would make good microscopists; and the slight extra trouble is amply compensated by the superior purity and intensity of the light and its extreme cleanliness, it being perfectly free from greasiness or disagreeable smell. As the lamp is always kept empty it is very convenient for carrying about when it is necessary to make observations away from home.

The illuminating apparatus commonly supplied with microscopes consists of the mirror below the stage, and a condensing lens either attached to the instrument or, as is to be preferred, on a separate stand. Other apparatus will be described in subsequent chapters.

The mirror is used for illuminating objects by directing light through them from beneath the stage, and is the usual, although not always the best, means of lighting an object, as it is one which we are unaccustomed to, and, without special precautions, is likely to lead into error. The mirror is capable of being moved out of the axis of the instrument, and light may be directed very obliquely upon the object, which is sometimes advantageous.

The condensing lens is used to concentrate light upon the object from above, and, when it can be employed, it is always preferable to commence an observation in this way rather than by means of transmitted light, as it accords more closely with our

every-day way of viewing objects: it is not our usual custom to hold up a substance we wish to examine and try to look through it, but we generally allow the light to fall naturally upon it. If a plano-convex lens, or "bull's-eye," be used as a condenser, it is necessary to be careful which side is turned to the source of light, otherwise it may be used in a position causing a great amount of spherical aberration and consequent loss of light. A plano-convex condenser should always have its curved side turned to the source of light when used for concentrating light upon an object. When used for rendering divergent rays, such as those of a lamp, parallel, which is often required when using apparatus hereafter to be described, the bull's-eye should be placed with its flat side to the lamp and at about the distance of its focal length.*

The beginner is recommended to commence his observations by endeavouring to procure a good and brilliant illumination with the condensing lens, looking at any easily procured objects, such as fragments of paper, feathers, sand, &c.; a humming-bird's feather or wing of a butterfly is particularly useful, as either of them presents very different appearances, according to the direction of the illuminating pencil, the iridescent colours of the first and

* Each lecture was followed by a practical demonstration, during which various objects, &c., were examined and processes in manipulation carried on under the superintendence of the lecturer and assistants. Much of the subject-matter of these demonstrations will be incorporated with the text; such portions as cannot be so given will be added at the end of the various chapters.

the imbricated structure of the second not being seen unless the light is made to fall in the proper direction. The light should be moved or the object turned round, and the varied appearances carefully noted. This precaution should be adopted with all objects viewed by reflected light.

In commencing observations by transmitted light, the student may profitably examine air-bubbles in water, easily procured by shaking up a little very weak gum-water in a bottle, and also globules of oil in water, of which milk furnishes a good and readily-procured example. A little of each of these should be placed on a separate slide, covered with a thin glass and examined by transmitted light, the air-bubbles with an inch objective; the milk may probably require a $\frac{1}{2}$ or $\frac{1}{4}$.

The leading characteristic of the air-bubble is its broad black margin when examined by transmitted light. If the laws of refraction are considered, it will be evident that a bubble of air in water will act precisely as a double concave lens, Fig. 4, B, and by its dispersive power scatter the rays of light, especially at the part where its power is greatest—the margin. The same effect may be produced, on a large scale, by holding to the light two plano-concave lenses of glass with their hollow sides placed together; this will almost exactly represent the air-bubble in water, differing only in the glass having a greater refractive power than the water in the microscopic slide, and dispersing the light rather more powerfully.

The oil globules of the milk exhibit a brilliant spot

of light in their centre when slightly beyond the focus of the microscope; this is owing to their being more refractive than the surrounding medium: their action is that of double convex lenses, Fig. 4, A, and the bright spot is an imperfect image of the source of illumination, which is rendered visible when the focus of the microscope coincides with that of the globule, which will be when the instrument is slightly above the focus for distinct vision of the globule.

These appearances should be carefully studied and remembered, as bubbles of air are among the most frequent of the instrusive substances to be met with during microscopical observations; cells filled with oil and globules of oil are also of frequent occurrence in tissues. Besides these, the student should make himself acquainted with the microscopical appearance of fibres of cotton, wool, flax, &c., hair of cats and other animals, all of which are frequently found in the dust of our apartments, and of course in our microscopical preparations, unless more than ordinary care is taken to prevent their intrusion, so that it is well to know them that they may not be mistaken for characteristic portions of the substance under observation, a not unlikely error on the part of inexperienced observers.

A sample of dust from the walls of an office in the Bank of England, where it had accumulated for more than ten years, consisted of about one-half cotton fibre, probably derived from abrasion of paper; the remainder consisted of fibres of wool and flax in small quantities, and soot and grit; molecular

motion was apparent when examined in water with a power of 400 diameters. An interesting paper "On the Microscopical Examination of Dust" was read by Mr. J. B. Dancer before the Literary and Philosophical Society of Manchester, January 26th, 1869.

CHAPTER II.

THE subject of the present chapter may be considered rather as mechanical than microscopical; in fact, it relates more to the workshop than to the study. It may, perhaps, seem strange to write about making apparatus and preparing materials in these days when nearly everything can be bought often better and more cheaply than it can be made at home, and when it is not as it was within the memory of many microscopists, who were obliged to cut their glass slides, or, at all events, to order a glazier to make them: but the more dexterous a person is with his fingers the better microscopist he is likely to make. Very often the success of an observation depends upon the observer being able to make some little contrivance to aid his researches, and it is for that purpose that the subject of the mechanics of the microscopical laboratory finds a place here.

The first material that engages the attention is glass. It comes under notice in several forms—the plates of glass upon which objects are mounted, the

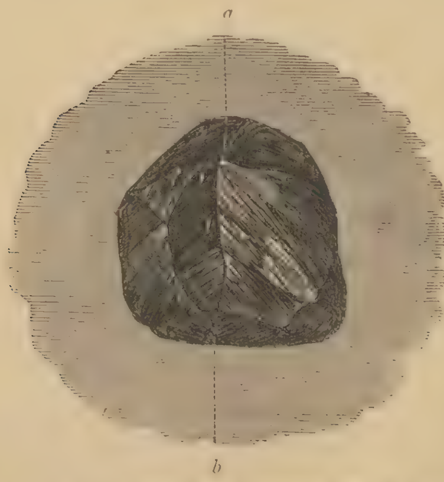
thin covering glass, and glass tubing. The glass generally used for mounting objects is a description of glass known as patent plate. Crown glass is sometimes used, but patent plate is perhaps the best. It is made from that commonly known by the name of cylinder glass, which is manufactured by the glass being blown, first of all, into a globe, then, by dexterous manipulation on the part of the workman, it is elongated, and a cylinder formed. This cylinder is ripped up, and put into an annealing oven: it unbends at the slit, and rolls itself out flat. In this state it is known as sheet or flatted glass. The glass then undergoes the same treatment as plate glass. It is ground down and polished, and then it becomes the patent plate. It is a thin glass, with a beautiful surface, so accurately worked that the plates will adhere together if pressed, just as good specimens of ordinary plate.

The tool used for cutting glass is the well-known glazier's diamond. It seems to have nothing in common with ordinary cutting tools: an incision or scratch with a diamond or other instrument, such as a flint or chilled-steel point, will not make the clean fracture we are so familiar with when the cutting diamond is used by a skilled hand. The diamond would seem rather to act by inducing some molecular displacement than by any actual penetrative power that it possesses. This view would seem to be supported by the appearance presented by the glass adjacent to a diamond cut when examined by the microscope with the aid of polarised light, which

shows that the glass has been subjected to some kind of strain. Rubies and sapphires, if worked to the form of the natural edges of the diamond crystal, will cut glass, but lose the power when the curved edge wears away. A very interesting paper on the fracture of glass and the action of the diamond, by Mr. F. H. Wenham, will be found in the *Microscopical Transactions* for 1868, p. 105. (See also *Holtzapffel*, "Turning, &c.," vol. i.)

There is some little art in using the cutting diamond: it is not any part of a diamond that will cut.

FIG. 13.



It is very easy, indeed, to scratch with a diamond, but it is only in certain directions that it will make the so-called cut. The glazier's diamond (Fig. 13),

when viewed under the binocular microscope, will be found to exhibit a well-defined and slightly curved edge, *a*, *b*. The diamond is carefully set so that this edge (which is a natural crystalline one) lies parallel with the oblong mounting, and, as the diamond requires to be held in an inclined position to secure a clean cut, the top of the setting is always bevelled to the proper angle. It is allowed a little play horizontally on a pivot, so that, upon placing the diamond in contact with a rule, it will always place itself in the cutting direction, and, by keeping the end of the setting parallel with the glass, it will be in a position for cutting. It is then drawn along; and those who have seen a glazier cut glass will remember the curious noise which accompanies the operation—something between a ringing and a hissing: the sound is very different from a scratch. The glass breaks at the place upon being bent. With a little practice, the cutting of glass will be very easy indeed; but it is not worth while, as a general practice, to cut slides, as they can now be bought at a cheap rate: it is chiefly for exceptional purposes that facilities for cutting glass are of value. Sometimes a piece of glass of extra size or unusual shape is required, and then time is often saved by being able to do the work, instead of waiting until the services of a glazier can be obtained.

The other kind of glass employed in mounting objects is the thin glass for covers. The details of its manufacture are unknown to me. It is remarkable for its extreme brittleness. In cutting, the

glazier's diamond is not employed, but a splinter known as the writing diamond. The operation is attended with some difficulty, as the glass is very likely to crack and star under the diamond. This is best prevented by placing the thin glass to be cut on a piece of wet plate-glass, which affords support, and effectually prevents splitting and cracking. As in the case of the 3×1 slides, it is hardly worth while to cut up squares and circles of thin glass, as it can be easily procured of the opticians already cut into the most useful sizes, or, if required in large quantities, of the wholesale glass warehouses. Of course pieces of unusual sizes and shapes are sometimes required, and then the power of cutting becomes of value.

The writing diamond is also used for making marks and writing on glass. Some persons write the names of their objects on the glass instead of on a label: it has the advantage of durability, but is not so legible as an inscription on paper.

Sometimes it is required to drill a hole in a piece of glass. This is a matter of no very difficult accomplishment. A good hard drill, if it is kept moistened with turpentine, will, with a small amount of patience and labour, eventually work its way through a piece of glass. Care should be taken that the glass rests upon a cork bed, or something soft, but yet firm, to give it sufficient support, or it may break just before the point of the drill makes its way through. Perhaps the best plan is to begin on the other side when the drill has penetrated about half-

way. Some persons are of opinion that dilute sulphuric acid, in the proportion of eight parts of water to one of acid, serves for moistening the drill better than turpentine. Of course the fluid used is the reverse of a lubricant: if oil were employed, the drill would not cut. The drills are best hardened by heating to redness and cooling suddenly with strong sulphuric acid. The edge requires working up from time to time upon an Arkansas stone, with oil. In drilling a thick piece of glass, the drill may require setting once or twice during the process; but I have never had any difficulty in drilling through a thick piece of plate.

The rough, sharp edges left on glass after cutting with the diamond may be removed by grinding with fine emery and water upon a smooth paving-stone or thick plate of zinc: the glass-cutters usually employ emery upon a "lap" or horizontal wheel.

For many cutting processes, tools made of corundum and shellac are very useful; this composition, in the form of wheels, files, hones, &c., of several degrees of fineness, can be obtained of Mr. D. Lyon, 43, St. John's Square, Clerkenwell, E.C. These tools, especially the wheels, are employed by dentists, in cutting and shaping the semi-vitrified porcelain used in the manufacture of artificial teeth. The use of the corundum composition in this country is comparatively recent, although it has been employed for centuries by the native jewellers of India.

Corundum is a crystalline mineral, identical, or nearly so, in composition with the sapphire, ruby,

topaz, and amethyst, equally hard, but wanting in transparency and lustre. Emery is nearly similar, but occurs in a granular form, and does not cut so well, although there are many purposes for which it is more serviceable than the harder corundum.

These tools must be plentifully supplied with water when in use, as, unless kept cool, they soon lose their shape, which would be the case if used dry, as they would rapidly heat and melt with the friction of rasping and grinding a hard substance.

Glass plates may be smoothed, and even rounded at the edges, with the greatest ease, with a corundum file, and almost as quickly as brass could be filed. A tapering tool is useful for enlarging a hole drilled in glass; and the hones serve for grinding sections of substances too hard for the ordinary stones. As the material becomes better known, many other uses will, no doubt, be found for it.

Glass is frequently used by the microscopist in another form, that of tube. It is chiefly employed in making the dipping tubes, with which objects such as free swimming animals and deposits in water are taken up, and for the pointed tubes, or pipettes, with which small portions of fluids are removed and deposited where they may be needed. The manufacture of these bent tubes, or pipettes, is not a matter of difficulty. The processes of drawing glass tube to points, and bending, are very frequent in the laboratory. The best source of heat is obtained from the Bunsen burner, which gives a very large flame without smoke and of great heating power

by the consumption of a mixture of air and coal gas. It can be obtained of the chemical instrument makers for a very small sum ; a spirit lamp, however, will answer the purpose tolerably well if the wick is a large one. A piece of glass tube, in which it is intended to make a bend, should be heated to a slight redness, and then carefully and slowly bent to the required angle. If an attempt is made to bend a tube suddenly, it will produce a choke, or contraction, in the bend. It is also necessary to heat a considerable length of tube. Pieces of glass tube are very easily detached, by making a notch on them with the edge of a file, and they are then sure to break straight across ; any length of glass tube can be cut off in this way. The process most frequently required to be performed by the microscopist is the drawing tubes out into pointed ends for pipettes. To effect this, heat the tube in the flame ; when the tube has become sufficiently soft, it can be drawn out to any length and fineness you please. The rough edge at the cut ends of tubing may be taken off by heating the ends in the flame, which will melt the edges and leave them rounded. This rounding of the edges is, perhaps, effected more rapidly by using a blowpipe, which facilitates the fusion of the glass. Sometimes a pipette curved as well as pointed is required ; there are many purposes for which it is extremely useful. This is easily made by a little variation of the other process ; while it is being drawn out, give it a skilful bend at the proper moment. Always keep tubes of glass revolving while they are being heated,

and do not heat them more than is absolutely necessary, as, when the tube is made very hot, it is extremely pliable, and likely to lose its shape. With a little ingenuity a number of useful things may be made out of glass tube. A variety of these pipettes will be found useful, and they are rather expensive to buy.

Glass, whether in the form of slides or thin glass, always requires cleaning. The best cleaning fluid is methylated spirit, which, as it is not subject to duty, and can be obtained cheaply, may be made free use of for this and nearly all the operations of the microscopist in which strong alcohol is required. Care must, however, be taken to obtain pure methylated spirit, and not what is commonly known as "methylated finish," which contains a small portion of shellac in solution, and is quite useless for all microscopical and laboratory purposes, and which is not unfrequently sold when methylated spirit is enquired for. I am indebted to the Rev. J. B. Reade for the history of this adulteration. Formerly, methylated alcohol was allowed to be sold without a licence; but certain persons, finding that it was cheap, and not being particular about the flavour of methylic ether, used it for making grog. This fact coming to the knowledge of the excise authorities, its sale by unlicensed dealers was prohibited, unless containing shellac in solution, a mixture which would not spoil it for its chief use, that of varnish making, while, upon mixture with water, the gum would be precipitated, making a very disagreeable turbid compound. There is no

difficulty in obtaining pure methylated alcohol in large towns, where one or more licensed dealers are generally to be found. It can be obtained perfectly pure, either in large or small quantities, of Messrs. Jackson and Townson, Bishopsgate Street, and of most other dealers in chemicals. It should not leave any residue upon evaporation, or become turbid when mixed with water; any spirit having these defects should not be used for microscopical purposes.

Great care should be taken that the cloths used for cleaning glass be perfectly free from soap or dirt, otherwise they will leave the surfaces of the slide covered with striæ. Old linen, or cotton cloths, are to be preferred to new ones; they should, before use, be boiled in water and common washing soda, to remove all soap left from former washings. They are then to be washed several times in clean water, until all trace of the soda is removed, and then dried, but not ironed, as the rough fluffy condition they will be left in is extremely favorable for cleaning glass. After the spirit is cleaned off with the cloth, any fibres that may be left from the cloth should be removed with a soft wash-leather.

Thin cover glass is treated in a similar manner, but, on account of its excessive brittleness, requires great care in cleaning. After a little practice, it is quite easy to rub it with the cloth and leather between the thumb and finger; but, should any difficulty be experienced, which may be the case with the thinnest kinds, it will be found that it can be rubbed with

considerable force, without injury, between two discs of wood covered with wash-leather. The great thing in rubbing a brittle substance is to support it well behind; this is the whole secret of cleaning thin glass between the finger and thumb.

For joining together pieces of glass, and for attaching metal to glass, the cement known as marine glue is usually employed. It consists ot india-rubber, shellac, and coal naphtha, combined in various proportions, according to the purpose for which it is intended to be used. It is, I believe, difficult to make in small quantities; but there is no trouble in obtaining it, as it is sold by most microscope makers. As this cement will only adhere to hot surfaces, it is necessary to have some means of applying a steady heat to the pieces of glass, &c., to be joined; and as this cannot be done by means of the unprotected flame of a lamp, a hot-plate is generally employed. This can be obtained, ready made, of the opticians; but a piece of thick brass plate, about 6 or 7 inches long and 2 inches wide, placed upon one of the rings of a retort stand, will answer admirably; it can be heated by means of a spirit lamp or gas flame placed underneath. Supposing, for example, it is required to attach a ring of glass or metal to a glass slide, to form a cell for an object to be mounted in. The glass slide is placed upon the hot-plate, first of all, at the part most distant from the lamp, to avoid breaking it by too sudden heating, and then moved gradually to the hotter part; the ring is also heated on the plate, a

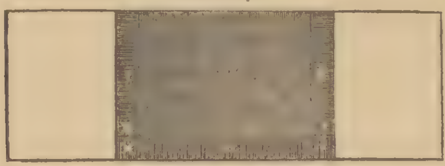
piece of marine glue is held on the point of a needle in a handle, or other convenient holder, and rubbed on the heated glass over the surface to which the ring is to be attached. When a sufficient portion of glue is melted on the glass, care being taken to heat the glue sufficiently for free working, while overheating amounting to boiling is to be avoided, the heated ring is then lifted on with a pair of forceps, which, for this and all purposes where they are likely to be made hot, should be of brass, or else an old pair of steel forceps, which are to be kept for such uses. The ring is then to be turned round backwards and forwards on the glass, to spead the cement equally, and then removed from the hot-plate and pressed on a piece of wood, to expel superfluous glue, and allowed a little time to set; when set, but still warm, the greater part of the cement can be scraped off with a blunt knife, a process much more difficult if it is allowed to become quite cold. A number of cells can be attached and roughly cleaned at one time, the plate next required being heated while the one cemented is being cleaned off. When quite cold, the slides can be thoroughly cleaned with a piece of rag and a free use of methylated spirit; they should then be rubbed bright with a clean cloth. Some persons use liquor potassæ for cleaning off superfluous marine glue; it does this very effectually, but not so rapidly as strong alcohol, and the operation is a rather unpleasant one, as the alkaline solution first softens, and then removes the skin from the fingers.

The adhesion of marine glue, and other cements,

to glass surfaces, is much improved by grinding, which gives the cement a better hold than it would have on a polished surface, although marine glue will adhere well to polished glass, provided the surface is free from grease, which may be insured by a cleaning with methylated spirit. The adhesion of two pieces of glass cemented with marine glue is so perfect that they generally break in any place rather than at the joint.

A very useful trough for viewing objects in fluid can be made with a slight amount of trouble. Cut in half an ordinary 3 × 1 slide (Fig. 14, shaded portion

FIG. 14.

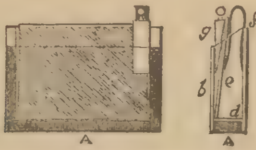


in centre). From this cut off the strip *a*, then the pieces *b* and *c*, and reject the centre piece, *d*. Before cutting, it is well to mark the adjacent edges with ink, as indicated in the figure, to prevent any mistake in putting them together afterwards. The three pieces *a*, *b*, and *c* are to be cemented with marine glue on the middle of a slide, and, as the cut portions, if replaced as directed, fit each other accurately, there is no occasion for grinding. The trough is completed by fastening an oblong piece of thin coverglass on the upper surface. For this purpose it is better not to use marine glue, as the cover frequently

requires removal, as, from its thinness, it is liable to be broken in cleaning. It can be best secured by the use of the following, known as "electrical cement," from its having been used to fasten various portions of electrical apparatus together:—Melt together five parts rosin, one part bees'-wax, one part red-ochre, two parts Canada balsam; mix well, and pour into pill-boxes of convenient size. This cement is most conveniently used with a miniature soldering bit, which is rendered more comfortable to use by its being balanced with a plug of lead in the handle. With a little practice, a very neat joint can be made. The cement is also useful for many other purposes, of which notice will be taken in the proper place.

Larger troughs, having sides of plate-glass, can be made by those who will take the necessary trouble. In this case, the surfaces to be cemented must be

FIG. 15.



accurately ground. Such vessels are very useful in looking over the results of pond-hunting with a low power, for the purpose of selecting such objects as may be required for more detailed observation. The troughs, of various shapes, can be purchased at most opticians.

The form represented in Fig. 15 is particularly

convenient, as by means of the whalebone spring, *f*, and the wedge, *g*, the space between the front glass, *b*, of the trough and the inclined plate, *c*, is capable of adjustment, so that an object can, when desired, be kept close to the front glass. These parts can be removed when a greater depth of water is required for larger objects.

A simple and useful contrivance, to be used as a growing-slide, has been described by Mr. C. J. Muller (*Monthly Microscopical Journal*, vol i., p. 174). The object of a growing-slide is to keep alive any minute water-plant or animal, the development of which it is

FIG. 16.

A

B

wished to observe. Many plans have been devised for this purpose, but none equal in simplicity or efficiency that now to be described.

An ordinary 3 × 1 slide (Fig. 16, A) is pierced with a minute hole at about 3-10ths of an inch from the centre on one side. When an object under investigation is

put upon it immersed in water, the thin glass cover is so placed as to include this hole, which should be near its margin. When it is desired to keep the specimen moist while off the stage of the microscope, the slide is placed in a small flat trough (B) in an oblique position, object uppermost, with one end (that nearest the hole) resting against the bottom of the vessel on one side, and the other resting upon the edge of it. Sufficient water is put into the vessel to admit of the liquid reaching within a ¼ or ½ an inch of the glass cover on the uppermost side, when it will be found that the water on the under side reaches beyond the centre of the slide, and consequently beyond the hole with which it is pierced. In this state, the object will remain moist so long as the trough contains a sufficient quantity of water. When required to be placed on the stage of the microscope, the water is easily wiped off the slide, without any disturbance of the object.

Mr. Muller's original trough was made of tin-plate, but, as this material is liable to rust when long in use, Mr. F. W. Gay has had them made of pewter and of an improved form, which has proved an effectual remedy for this defect. Thus constructed, they are to be obtained of Mr. C. Baker, Holborn.

The process of attaching cells to plates of glass has been given; but nothing has been said about the material of the rings forming the cells. When required of some considerable depth, rings made of slices cut from thick glass tubing answer admirably. If square or oblong cells are required, they can be

cut from tubes of suitable form. Very useful cells are now made by Mr. Collins of pure tin of various thicknesses, from that of thin writing-paper up to that of a thick tube cell: several sizes can also be procured in each thickness. Tin is not acted upon by any of the fluids used in preserving microscopical objects, and has the advantage of being much cheaper than glass, and at the same time equally efficient. Cells of unusual form can readily be cut from the sheet-tin with a penknife or pair of scissors, and circles can readily be punched. The adhesion of the cover-glass is improved, and the process of mounting in fluid much facilitated, by grinding the upper surface of the cell after it is attached to the slide with water upon a Water-of-Ayr stone, as suggested by Dr. Carpenter. This gives a beautiful surface, and ensures the perfect fit of the cover, and renders the closing of the cell a matter of greater certainty than it would be if the natural surface of the metal were used.

Some very useful aids to the examination of microscopical objects, and which can readily be made by the exercise of the smallest amount of mechanical ingenuity, are described by Mr. S. J. McIntire, in the *Transactions of the Quekett Microscopical Club*, vol. i., p. 69. One of these is of such general application that it will be well to describe it. A piece of sound sheet cork, about 2 in. by 3½, or other convenient size, and of a thickness suited to the purpose for which it is intended, is perforated with an oval or circular hole; this may easily be cut with a penknife or sharp chisel, and the edges finished with a

file. The cork is placed between two pieces of glass of similar size, the lower one being covered with a few layers of pink blotting paper, and the whole contrivance kept together with two india-rubber rings. The cell so constructed is used for keeping alive small insects that inhabit damp situations, such as *Poduræ*. The moisture is readily supplied by dipping the end of the slide into water, which is absorbed and retained by the blotting paper. The proper food of the insects can be placed in the cell. By the aid of this simple contrivance, Mr. McIntire has been enabled to make some most interesting observations on the habits of the *Poduræ*, which have been kept living in these cells for many months. This plan admits of modification to suit the object under observation. In the author's researches on the blow-fly, it was necessary to use thin glass, and to have the means of viewing the object on either side; this was accomplished by cutting a rectangular hole in a suitable piece of cork, placing the thin glass on either side, and securing it by bending on its edges strips of the sheet tin used for making cells; these had been inserted in the cork, which effectually fastened the glass in a somewhat similar manner to that by which a stone is set by jewellers, and readily permitted its removal when required.

Among the tools employed by the microscopist, none are more generally in request than needles of various sizes and forms. They are frequently required of various curvatures; this bending can readily be performed by the microscopist himself.

If a needle is heated to redness in the flame of a spirit-lamp, and allowed to cool, it can easily be bent or twisted into any required form. Steel so treated, if heated again to redness and suddenly cooled in water, becomes excessively hard and brittle; in this condition, it is capable of scratching glass, but is too fragile for dissecting instruments. The right temper for the dissecting needles is obtained by heating and cooling in tallow or oil; this, with needles, may be readily done in a common tallow (not composite or paraffin) candle. While the needle is soft, it may, by the exercise of a little dexterity, be hammered out so as to form a small knife, or lancet, which can then be hardened so as to take a cutting edge; many useful instruments can also be made out of small pieces of steel. Needles and cutting instruments are best sharpened upon a very hard, white stone, known at the tool shops as Arkansas oil-stone; it cuts very rapidly, and gives an extremely fine edge. Scissors, when blunt, may readily be sharpened on the oil-stone, by opening the blades and rubbing them on the stone, holding them nearly upright. The burr produced by this operation need not be ground off, as it is soon removed when the blades are worked together; the screw is to be tightened if required. For delicate dissections, the steadiest cutting instrument is a kind of scissors, made almost exactly like a minute pair of sheep shears, and known as the microtome; in use, it feels very much as if the fingers were extended and armed with cutting edges. There is

hardly any other cutting instrument so much under the control of the operator.

The best handles for needles and other small instruments are made of cedar pen-holders, into which the needle, with the eye broken of, is inserted with a pair of pliers. Very convenient handles, which have the advantage of allowing the needles to be removed at pleasure, are to be purchased at fancy warehouses; they are used for holding crochet hooks; they are improved by the removal of the ivory handle, and the substitution of one made of a cedar pen-holder, which can easily be attached to the metal socket with electrical cement, and will be found to be lighter and more pleasant in use.

CHAPTER III.

THE processes connected with the preparation and preservation of microscopical objects have always occupied a considerable space in nearly every work on the use of the instrument. The subject is one of general interest, and the importance of being able to preserve specimens for future reference can scarcely be overrated.

The simplest of these processes, and also the oldest, is that known as "dry-mounting."

The objects suitable for mounting dry are those which can be preserved in air and are capable of being dried without injury to their structure. The ways of mounting are extremely numerous, and are principally means of protection from the great enemies of all natural history preparations—damp and dust. One of the oldest ways of mounting objects was upon discs punched from a compound sheet of card and wash-leather, through which a pin was run for convenience of holding in the stage forceps and keeping in a cork-bottomed drawer. This plan of

mounting was abandoned when the lieberkuhn fell into disuse, but it has since been revived in a new form by the late Richard Beck, who invented a very ingenious instrument for holding the small

FIG. 17.

discs of metal and turning them into any required position. This is an extremely useful piece of apparatus, as it is often required to turn an object into several positions for the thorough examination of its structure. So perfectly is this accomplished, that five out of the six sides of a cube may be examined by means of the revolving disc-holder. This instrument has supplied a want created by the introduction of the binocular microscope, as the greater focal depth and stereoscopic effect given by it has rendered advantageous frequent changes of the position of objects, for which this contrivance most effectually provides. For the keeping of the discs from the influence of dust and damp, he contrived a close-fitting screw-box, having suitable arrangements for the reception of twenty-four discs.

Great use has also been made by some observers of open cells. These consist of a hole bored in a 3×1 slide of wood, with a piece of card-board glued

to the bottom, the objects being fastened with a little gum. This answers very well with objects not liable to injury from exposure, such as shells; but, for most purposes, it is necessary to close up the object, and this, in many instances, is done in a manner very detrimental to its preservation. Wherever paper and paste or gum are used, various fungi and confervæ are nearly sure to make their appearance, unless special precautions, such as saturating the paper with, and mixing in the gum, a small quantity of corrosive sublimate. The microscopical fungi are doubtless interesting plants, but, when they grow over valuable preparations, we feel them to be a nuisance, and decidedly in the way.

Some microscopists, avoiding the use of paste, gum, and paper for securing the cover to the slide, have made use of varnishes of several kinds. These generally have the defect, if thin, of running in between the glass and cover and spoiling the object, and, if thickened with a solid substance, such as lamp-black or vermillion, of becoming porous after a time. Some of the fluid medium of the varnish, also, is liable, in drying, to rise in vapour within the cell, and condense on the cover, interfering with the distinct view of the object. The vapour of turpentine or naphtha, however, is in no way otherwise detrimental, as it tends rather to the preservation than the destruction of tissues.

The electrical cement previously described (Chapter ii., p. 45) is free from this defect, and furnishes a means of rapidly mounting objects

either with or without a cell. If the object is very thin and flat, it may be placed upon a slide, and a thin glass cover put over it. Both having been carefully cleaned, one of the spring clips made of wire and cork (which are to be procured of most opticians) can be used to hold the cover in place while the cement is being run round it with the little brass bit. The bit should not be made too hot, or it will not hold the cement. After the cover has been fastened down, the rough cement can be smoothed by passing over it a clean bit, heated rather more than is required for laying on the cement. The bit is easily cleaned by wiping while hot upon a piece of blotting-paper. The first attempts, no doubt, will be far from elegant in appearance ; but, after a little practice, great neatness may be attained. This process is also available for attaching the cover to cells of metal or glass, which must be used with dry-mounted objects whenever their thickness is such as to require it. This mode was formerly much employed, but was abandoned on account of the brittleness of the cement. This may be remedied by varnishing, when the cement has become hard, with gold-size, which is remarkable for the tenacity with which it adheres to glass and its toughness and non-liability to crack. Respecting the properties of this varnish, more will be said in the chapters relating to fluid-mounting. This system of compound cementing answers perfectly ; the electrical cement having, in the first instance, no tendency to run in, and the gold-size effectually keeping it from separa-

ting from the glass. If the natural red colour of the electrical cement is objected to, a black finish can best be obtained by the use of lamp-black as prepared for water-colour painting. The best form is that in tubes. A little of this is pressed from the tube, and, if too thick, a small quantity of water added. With this the varnished surface is thickly painted, and, when dry, a few coats of gold-size will keep it from being washed off. The result is a dense, lustrous black, very superior in effect and durability to that produced by a black varnish. This finish is equally available for fluid and balsam mountings.

If the object cannot be kept in its place by the pressure of the cover glass, it will require fastening. If the object will bear a slight amount of heat, a small spot of electrical cement may be placed on the glass, melted by holding over a lamp, and, while soft, the object fixed. Or the thick varnish composed of shellac and wood-naphtha, sold at most varnish-shops as liquid glue or "patent knotting varnish," will be found useful for this and other purposes to be mentioned hereafter. Care must be taken to allow the naphtha time to evaporate, or its vapour will obscure the cover. While this drying is taking place, the slide may be turned face downwards over a large pill-box, or the cover put on, and kept in place with a spot or two of electrical cement, deferring the completion until the varnish has dried.

It is not necessary to employ any kind of black background for opaque objects, the best background being that of the dark-well beneath the stage, formed

by bringing round that part of the diaphragm-plate which has no hole, and so closing up the aperture. If a black patch is used, it prevents advantage being taken of various kinds of illumination from beneath, which are often of great service, while the mounting on clear glass is in no way detrimental to the view of an object lighted from above.

It is necessary that the object to be mounted should be perfectly dry before it is placed in the cell, otherwise moisture will, sooner or later, make itself apparent.

Most objects can be dried by the application of a moderate heat. If wrapped up in a piece of paper, and placed inside the fender, in an hour or so they will be found to be effectually dried. A Seidlitz-powder box answers extremely well for this kind of drying: it can be still more effectually accomplished by means of the well-known hot-water oven.

There are cases, however, where heat is inadmissible, especially with delicate tissues. The desiccation of these is best accomplished in a vacuum. The substance to be dried is placed under the receiver of an air-pump; the air is exhausted, and, under these conditions, it will give off vapour at a much lower temperature than under ordinary atmospheric pressure. It is only necessary to provide some means of absorbing the watery vapour as fast as it is given off—such as concentrated sulphuric acid or dry lime.

Another, and very effectual mode of drying delicate tissues without heat, is the process described in the Chemical News (vol. xiii., p. 122), translated from

Zeitsch. fur Anal. Chemie. This process, which is quite new so far as its application to microscopical purposes is concerned, consists in immersing the substance to be dried in ether in the presence of dry chloride of calcium. The apparatus employed is simple, consisting of a wide-mouthed stoppered bottle, at the bottom of which is placed some chloride of calcium. A slice from the bowl of a tobacco-pipe forms a support for a Berlin crucible and cover, in which the substance to be dried is placed. The whole is then covered with ether (the methylated answers very well for the purpose), and the mouth of the bottle closed. The ether absorbs water from the tissue, which is again absorbed by the chloride of calcium, and the process goes on without attention until the chloride of calcium ceases to absorb. The results, as far as at present ascertained, have been very satisfactory. Cellular tissue (fresh potatoe) has been dried without any contraction. Flies' heads have contracted less than by drying in air; the eyes were in very perfect condition, and gave good results upon a section being cut; the striation on the muscular fibre was perfectly preserved. A small spider, treated by this process, was dried without any shrinking of the abdomen. Those substances which are injuriously acted upon by ether cannot, of course, be dried by this process; but it is evidently a very valuable addition to the microscopist's resources.

When the object is removed from the drying apparatus, the ether dries off in a few seconds. If it

is required to preserve the object in balsam, it can either be mounted at once, wet, with ether, or transferred to benzol or turpentine.

In the old days of microscopic manipulation, no means was known of preserving objects but that of mounting them dry. The usual plan was to mount about six objects in an ivory slide, between discs of mica, secured with a brass ring: thin glass was unknown at that time. Mounting in Canada-balsam was, after this, hailed as a very great improvement. Whether the idea was suggested or not by insects preserved in amber there are no means of ascertaining. Very often ideas are suggested by natural occurrences, and it would seem likely that some attempt might be made to imitate these specimens of Nature's mounting. Gum and various varnishes were tried, until, at last, Canada balsam was found to succeed.

Canada balsam may be considered as a natural varnish. It is one of the substances known as oleoresins, and is, according to the "Micrographic Dictionary," the product of *Pinus Balsamea*, although, possibly, it may be obtained from more species of the *Coniferæ* than one: something nearly similar is found in every pine-wood—the turpentine exuding from many of the trees. Canada balsam, like some other varnishes, possesses a power of drying more or less readily according to circumstances. It dries more quickly at a moderate heat than otherwise; is readily soluble in ether, turpentine, and benzol; and possesses the advantage of being highly refractive—nearly as much so as glass, thereby rendering the

view of the edges of objects clearer when examined by transmitted light, by diminishing the diffraction—that power which light seems to have of going round a corner under certain circumstances, and which causes objects, under high powers, to show ill-defined margins when viewed in air. Canada balsam is also capable of soaking into tissues, and rendering them much more transparent than they would otherwise be. A much clearer view of the interior of semi-opaque objects, and, frequently, of objects that are too dense to transmit any light, can be obtained by its means than possibly could be without it. But, while it has the advantage of rendering tissues very transparent, and, at the same time, preserving them in an undoubtedly permanent manner, it is sometimes liable to render them almost invisible by inducing an excessive transparency; it is, also, applicable only to those substances that can be dried without injury. This, of course, prohibits its use with a very large class of tissues, the minute details of many animal and vegetable structures being obliterated by drying, either by ordinary desiccative processes, or the absorption of their water by means of strong alcohol;—a process which frequently induces great contraction in a substance treated with it, but which is sometimes taken advantage of when it is required to harden a soft tissue.

The process of mounting in Canada balsam is not a very difficult one. The chief obstacles are the presence of damp and air. A few air-bubbles in a preparation are of little consequence; but, if the

preparation should be mounted at all damp, it will almost invariably fail. Damp makes itself known by a kind of fog surrounding the object.

If the object to be mounted can be dried on the slide, the mounting is extremely easy. Place upon it a drop of Canada balsam; warm gently over the lamp chimney until it runs, but do not let it boil; then place the cover glass on with the forceps, letting one edge touch first and bringing the cover down gradually, so as to expel any floating air-bubbles with the surplus balsam. Should there be any doubt about the penetration of the balsam, the object may advantageously be moistened with turpentine, or, still better, camphine, if it is to be procured. Objects especially liable to retain air should be prepared by a prolonged soaking in turpentine or benzol; and, in obstinate cases, the air-pump may be used with advantage to aid the saturation with the fluid. Small air-bubbles in a preparation need not be a source of anxiety, as they speedily disappear by absorption.

Sometimes the object may be placed upon the slide, the cover clipped down, and some balsam placed at the edge, which is then melted, and allowed to run in by capillary attraction. This plan has the advantage of causing little or no disturbance in the position of an object, and should always be used, if there is any tendency to curl upon the application of heat.

In some cases, the presence of air within a tissue is an advantage instead of a detriment. The lacunæ

and canaliculi in sections of bone, and the tracheal tubes of insects are much better shown when they are, as it were, injected with air. To retain the air, the treatment must be the reverse of that described. The balsam must be the thickest that can be procured, and the mounting done cold, or with the application of the smallest available amount of heat.

The surplus balsam around the edges of the cover will require to be cleaned off; but this must not be attempted until it has become hard and firm. The hardening of the balsam may be much accelerated by the application of heat. The inside of a fender is a very convenient place for drying balsam-mounted slides. A drying apparatus for effecting this more quickly is described by Mr. D. E. Goddard, in the *Transactions of the Microscopical Society of London*, January, 1864, p. 45.

The simplest way of removing the surplus balsam is to make it very hard, and then wet the slide, and scrape away the balsam with a wet knife. It comes off very readily, and leaves the slide so clean that it can be easily finished with a rag and a little methylated spirit. Where the balsam is not very hard, it is better to scrape away as much as possible with a hot knife, and remove the remainder with alcohol, being very careful not to disturb the cover. The knife for scraping the slide should be softened by heating to redness and allowing it to cool, or it will scratch the glass.

The forceps and needles may be cleaned from balsam by heating in a spirit-lamp, and wiping with

rag or blotting-paper. The forceps should be common brass ones, as steel would soon be spoiled, and the needles kept for this particular purpose, as they are useless for any other. Balsam may be removed from the fingers by a free use of methylated spirit.

Canada balsam is best preserved for use in the collapsible tin-tubes used for containing oil-colours. As already mentioned, air is largely absorbed by balsam; indeed, most varnishes dry quite as much by the absorption of oxygen as by evaporation. The advantage of the tube as a receptacle is that the balsam is kept quite close to the top of the tube, and no air allowed to remain there, so the balsam may be preserved in a perfectly fluid state for a long period. Balsam has been kept for two years in these tubes, and been as limpid as when the tube was filled; while, in bottles, the balsam rapidly hardens, and becomes useless if long kept. The tubes have also the advantage of cleanliness in use: the supply is obtained by squeezing out the quantity required; the use of a dipper, an endless source of dirt and introduction of foreign substances, being dispensed with. Should a little balsam ooze out around the screw-cap, it can be scraped away with a hot knife. These tubes also form convenient receptacles for varnishes which are liable to injury by being exposed to the air—such as gold-size. They do not answer for varnishes made with naphtha or spirit, as these varnishes dry entirely by evaporation, and soon fasten down the cap.

Solutions of balsam in various media have been much used by some microscopists. They have the advantage of allowing the mounting of an object to be effected without the employment of heat, a great desideratum in many cases. Chloroform has been the medium hitherto employed for dissolving the balsam, which is previously exposed to a slow heat, until it is dried into a hard, resinous mass. It has been found, however, that objects mounted in this solution have frequently become cloudy, and that the solution, if kept for a considerable period, becomes turbid. Dr. Bastian recommends the use of benzol as a solvent, on the ground of its greater stability. He has made great use of the solution as a medium for making preparations of nervous tissue. A detailed account of his processes will be found in the *Monthly Microscopical Journal*, vol. i., p. 94.

The solution of balsam and benzol is most conveniently kept in a wide-mouthed bottle, with a ground cap instead of a stopper, which will allow a small pipette to be kept in the bottle. Should the fluid become too thick from evaporation, a little more benzol may be added.

Besides the use of balsam as a mounting medium, it is useful as a cement for a special set of purposes. The microscopist who makes the osseous tissues, rocks, or hard substances in general his particular study, will often require thin sections.

The preparation of a bone section will serve very well as an example of section-cutting, and polishing in general. It is required to make a very thin

section of a recent bone, polished on both sides, to be mounted dry. The bone is to be cut into thin slices with a watch-spring saw. A level surface is then to be made on one side, by grinding down with water on a piece of blue-stone, or Water-of-Ayr. If the slice is very rough, time may be saved by using a file in the first instance, and finishing on the stone. The fingers may be protected from the action of the stone by bedding the rough section in a piece of cork.

The bone slices are to be cemented with Canada balsam, by their ground sides, to pieces of thick plate-glass; 1½ inches by ¾ of an inch is a convenient size for general use. The chief art consists in using the balsam of the right degree of hardness. A drop of balsam is to be placed on one of the slips, boiled on the hot plate, and allowed to cool. If, when cold, it is just capable of receiving a slight impression of the thumb-nail when pressed hard, it will do. If too soft, it must be heated again, and allowed to cool, and the process repeated, if necessary, until the right degree is obtained. If the balsam is not hardened sufficiently, it will clog the stone in the subsequent process; and, if too hard, it is liable to chip off along with the partially-finished section during the grinding. The piece of bone, cemented in its balsam bed, is to be ground down with water until the surface is levelled. It is then to be polished, so that no scratches appear upon it when examined under the microscope. This is done with putty-powder (oxide of tin, and not in any way connected with glaziers' putty), used with water upon a

wash-leather strop. When the polishing is completed, the section is to be removed from the glass, which can be done by dropping it into a bottle of benzol, which will dissolve the hardened balsam, and release the section in a few minutes. A wide-mouthed stoppered bottle is convenient for this purpose, and the pieces of plate-glass are cut of the small size recommended, in order that they may be easily placed in and removed from the bottle. The half-finished section is now to be cemented to another balsam-bed, and ground down until it is sufficiently thin. With practice, 1-500th of an inch may be attained with a tough substance like bone. The author has approached this thickness even with fossil ganoid scales from the Weald clay. At first, it is well not to attempt too thin a section, and to practise on some material of which a large supply can be obtained. When ground sufficiently thin, the second surface is to be polished, and then detached as before, and afterwards washed in clean benzol, to remove all traces of balsam. The finished sections, when the benzol has dried off, are to be mounted dry by one of the usual processes.

Sections to be mounted in balsam will not require to be polished, as the balsam fills up, and, by its refractive power, apparently obliterates the scratches left by the grindstone. Other hard substances are treated in a nearly similar manner. Fossil bones and teeth, from their extreme brittleness, will require greater care in grinding, and, from their dark colour, must often be mounted in balsam, instead of dry.

This is also necessary when they have a tendency to disintegrate. For very hard substances, such as teeth, the Arkansas stone would be of great service; but, unfortunately, it does not cut well when used with water, and, if oil is employed, the balsam is softened. A process devised by Dr. Christopher Johnstone about ten years ago, and published in *Silliman's Journal*, gives a process by which an oil-stone can be employed. The cement used is isinglass jelly, made with alcohol. Use is made of thin paper, as a guard against grinding away the section—an accident of frequent occurrence with beginners. The grinding is performed upon an Arkansas stone, with oil, and hot water is used to detach the section. The grease can be extracted with benzol. A detailed account of the process is given in the *Journal of the Quekett Microscopical Club*, 1869, p. 201. Accounts of the mode of cutting rock-sections, by J. B. Jordan, will be found in the same journal, p. 186, and, by D. Forbes, F.R.S, in the *Monthly Microscopical Journal*, vol. i., p. 240. The process of cutting sections of still harder substances, such as gems, is described by Mr. H. C. Sorby in the *Monthly Microscopical Journal*, vol. i., p. 220. Grindstones and polishing powders of various kinds can be obtained at the better class of tool shops, as Holtzapffel's, Buck's, Fenn's, &c.

Although it is the usual custom to cover slides containing dry and balsam mounted objects with paper, it is preferable to leave them without. A balsam-mounted preparation, well cleaned, and

mounted on a piece of good patent plate with polished edges, is far neater than when covered with paper, which too often only serves to conceal an inferior quality of glass.

CHAPTER IV.

THE microscopist, in the course of his studies, will find a very large class of substances for which the processes described in the preceding chapter are of no avail, owing to the impossibility of drying them without materially affecting their structure. The preservation of such substances has always been a matter of some trouble; and beginners are frequently deterred from attempting the processes of fluid mounting by supposing that the difficulties are of an insurmountable kind.

There is also a prejudice against objects mounted in fluid, owing to their supposed want of durability. There is, no doubt, some ground for this objection if the ordinary fluid-mounted objects only are considered. These are of necessity manufactured cheaply and in large numbers, and but little care can be bestowed upon their preparation. But, if the cabinets of our best manipulators are examined, the evidence will be found rather in favour of than against fluid mounting, provided care be taken to

adopt the best processes, and carry them out carefully; the causes of failure being rather attributable to bad workmanship than to defects in the mode of preparation. Instances are on record of objects mounted in fluid as long ago as twenty years being still in good preservation.

The subject naturally divides itself into two parts; the processes connected with the enclosing of the object in its cell, and the consideration of the nature of the fluid media employed as preservatives.

The object to be mounted in fluid will nearly always require some previous preparation, excepting in those cases where it is free from included air, and the fluids contained in its tissues are readily miscible with the preservative employed. This preparation consists in keeping the tissues required for preservation immersed either in the fluid in which they are to be mounted, or some other which is capable of combining with it without injurious chemical change. This soaking will occasionally occupy a considerable time; but it may be materially expedited by making use of the air-pump, which will ensure the saturation of the tissue, and assist in the removal of air that may be held within it. The process is of the same kind as that adopted on the large scale for the preservation of railway-sleepers, by impregnating them with creosote; and, in another operation (one that more closely approaches the subject under consideration), Manfield's patent for making pickles, in which the vegetables to be treated are saturated in a few minutes with vinegar, by being

submitted to its action in a vessel from which the air has been exhausted; a process which took so long a time in the ordinary way, that manufacturers, to save the loss of capital involved in using vinegar, employed brine, which was afterwards removed by strong acetic acid, greatly to the detriment of the resulting manufacture, both as to flavour and wholesomeness. This is now obviated by the new process, the pickles produced by which closely resemble those made at home.

Although the air-pump is useful where substances peculiarly liable to retain air (such as large anatomical preparations) are being operated upon, its use can generally be dispensed with for ordinary purposes, a prolonged soaking being sufficient in most cases.

In mounting an object in fluid, a cell of suitable size and depth is to be selected, and care taken that it is properly cleaned. It is then filled with the mounting fluid, and should be rather over than under filled. The object is now placed in the cell, unless circumstances have rendered it advisable that this should be done previously. The preparation, at this stage, should be carefully examined, with a view to the detection of air-bubbles. They are especially liable to adhere to the lower part of the cell, where it joins the glass slide. They are best dislodged by drawing the point of a needle round the interior of the cell. Floating bubbles may be broken or removed by lightly touching with a pointed fragment of blotting-paper.

The cover glass is to be placed upon the cell as directed in balsam mounting—letting one edge touch the cell first; and, as in that process care was taken to keep everything dry, in fluid mounting we should adopt the opposite course of treatment. To secure the adhesion of the mounting fluid to the cover, and lessen the chance of including an air-bubble, it is well to moisten the cover by breathing on it just before placing it on the cell.

The surplus fluid is best removed, in the first instance, by drawing it off with a curved and sharp-pointed pipette, made in the form of an ordinary blow-pipe. The use of this contrivance will generally allow the floating cover to be brought in contact with the top of the cell without the risk of flooding its upper surface, which is nearly sure to take place when the cover is pressed down suddenly, and will give trouble to remove when viscid fluids like glycerine and oil are used. When as much of the fluid is removed as can be conveniently taken up with the pipette, the rest is absorbed by the careful use of fragments of blotting-paper. Care must be taken not to carry this process too far, as, if too much of the fluid is absorbed, an air-bubble may enter, which will necessitate the removal of the cover and a repetition of the operation. The moisture being cleaned off the outside, the cell is ready to receive its first coat of varnish, which is to be applied with a small brush, and care should be taken to fill the angle at the contact of the cover and cell, and to include in the ring of varnish a small portion of the edge of the

cover. This first coat of varnish must be put on by hand, as the adhesion of the cover is too slight to bear the action of the turn-table; this machine, however, may be employed with advantage in laying on the second and subsequent coats, as, by its use, greater neatness and rapidity are attained than are possible by painting on the varnish by hand.

The best and most durable cement for securing the covers of objects mounted in fluid is the varnish known as japan gold-size, the principal constituent of which is boiled linseed-oil. It is easily obtained at any varnish shop. It is best kept for use in the collapsible tubes recommended for holding Canada balsam. If kept in a bottle, it absorbs air, thickens, and loses, to some extent, its drying properties. This varnish is remarkable for its elasticity and toughness when dry, which may readily be proved by scraping a portion, which will be found to come away in shreds instead of chipping, as many other varnishes do. Glycerine and castor-oil, both valuable mounting fluids, have the unfortunate property of dissolving gold-size; therefore, in using these media, it is necessary, before putting on the coatings of gold-size, to apply two or three coatings of the liquid glue previously mentioned. This varnish is impervious to oil and glycerine, but is too brittle when dry to be trusted alone. The liquid glue will be found effectually to protect the gold-size, with which the preparation is to be finished. This precaution is not required when using media which do not injuriously affect gold-size, such as weak

alcohol and water, saline solutions, camphor and creosote water, &c.

Some microscopists make use of asphalte or Brunswick black for securing the cover. They have the fault of being brittle, which, however, is said by Dr. Beale to be remedied by the admixture of a small portion of solution of india-rubber in naphtha. The author's experience of this cement is rather unfavourable. It may, however, be owing to having used a bad specimen; as it is probable that many kinds of Brunswick black are manufactured, and they are likely to vary extremely in quality. However, as gold-size is so reliable a cement, and so easily procured, there is no occasion to risk the use of a varnish whose properties are somewhat uncertain.

Should the mounting fluid be one which leaves a deposit on drying (which is the case with saline solutions), or be difficult to clean off (like glycerine), after the first coat of varnish is dry, the slide should be washed, either by holding under a partially-open tap, or by means of the ordinary wash-bottle. If this precaution is not taken, the adhesion of the cement is rendered uncertain, and neglect of this matter is a not unfrequent cause of leakage. If necessary, this washing must be repeated after the second coat of varnish. With oil, a somewhat different treatment is needed. The cleaning is best effected with a camels'-hair brush, charged with turpentine or benzol.

The slide should not be put away in the cabinet

until it has received at least six or eight coats of gold-size. No varnish should be laid on thickly, otherwise it is liable to remain fluid in the interior, although apparently hard outside.

In commencing the practice of fluid mounting, it will be advisable for the student to make his first trials with some such fluid as camphor-water or diluted alcohol, as the difficulties of cleaning, &c.' are much less than with saline solutions or glycerine.

A very ingenious process of fluid mounting forms the subject of a communication by Mr. T. C. White to the Quekett Microscopical Club (*Journal of the Quekett Microscopical Club*, vol. i., p. 147). He forms a cell with a thick varnish, made by dissolving gum damar in benzol. This is done by holding a brush charged with it against a slide while revolving on the turn-table. The cell will be ready in a few minutes, as it is used while half dry. The fluid and object are placed in the cell, and the cover glass put on, and pressed down into the cement, which adheres most tenaciously to wet glass. The surplus fluid is to be removed with blotting-paper, which may be used with the greatest freedom, as the glass is held very firmly by the damar varnish; another coat of this is applied by means of the turn-table, and the slide is completed. It would no doubt be more secure if finished with a few coats of gold-size. This process can only be used by those who are somewhat expert, as, should the first attempt fail, the cover cannot be removed and the process repeated. It is a very expeditious mode of mounting, and is likely,

in some cases, to prove of great value. Mr. White states that he has had slides mounted for two years which are still perfectly sound and free from air-bubbles. The solution of damar may also be used as a very efficient substitute for the mixture of balsam and benzol. It is, like most varnishes, rather troublesome to make, as, owing to the impurities usually contained in the gum, the varnish requires straining; a somewhat difficult matter with so volatile a solvent as benzol.

The durability of objects, however mounted, is much influenced by the manner of storing them. Racked boxes and drawers are the worst possible receptacles, as from the vertical position of the slides they are liable to serious injury, those in fluid being likely to become leaky, and the balsam specimens sliding down, frequently, cover and all. Arrangements should be made for keeping the objects flat, which is now always done in well constructed cabinets; it is also a great advantage to be able to see every slide, which is impossible in a racked box, and often causes much loss of time in searching for an object. For the convenience of those for whom the usual cabinets are too costly, Mr. Piper has invented some very ingenious trays, in which slides are placed horizontally; besides the merit of cheapness, they have the advantage of being extremely convenient. Five or six of these trays, with a mill-board at the top and bottom, may be fastened together with a couple of India-rubber rings, and any vacant shelf room utilised for the storage of objects; a similar

bundle of two or three trays is very convenient for carrying a small selection of objects in the pocket. Dr. Carpenter has used these trays placed in wooden cases made to resemble books, a very convenient way when bookshelves are vacant to receive them.

The chief difficulty of fluid mounting will be found not to consist so much in the mechanical process of closing the object perfectly in its cell, as in the selection of a fluid suitable for its preservation.

A fluid which may be considered as a perfect medium—that is, one capable of preserving substances for an unlimited period without change, is at present unknown, and it is more than doubtful whether the discovery of such a fluid would be altogether an advantage, as use is frequently made of what some may consider the defects of preservative fluids ; the alterations they induce in tissues submitted to their action often revealing facts of great importance. Some media are valuable, because they soak into tissues and render them transparent ; this is the case to such an extent with glycerine, that Dr. Beale very appropriately calls it "The Canada balsam of moist tissues." Others are used for quite the opposite purpose, because they induce opacity, and very frequently do so partially, bringing out details somewhat in the same manner as is done by the colouring of a map, and which, without such aid, would be very imperfectly distinguished. Others are slightly corrosive, and clear away parts wished to be got rid of for the sake of bringing others more prominently into view.

In mentioning some of the very numerous media which have been used for mounting, the results can only be stated generally, and no fixed set of rules can be given, as the whole subject is at present in too imperfect a state. Much good might be done by observers mounting a series of the same object in different media, carefully labelling each slide with the date of mounting and the nature of the medium employed, and from time to time noticing and recording the result.

One of the great difficulties affecting the mounting of objects in fluid, arises from endosmotic action. When two fluids of different densities are separated by a permeable membrane, they will pass through and mix at very unequal rates. Supposing some dense fluid, like glycerine, enclosed in a bladder and immersed in water, the water would flow into the bladder faster than the glycerine made its way out, the result would be the expansion of the bladder. This is called endosmosis: the reverse action is known as exosmosis. With a view to observing practically the result of these actions, the student is recommended to obtain a specimen of some fresh-water conferva, such as are abundant in nearly every pond or aquarium. A portion of this conferva should be placed on a slide in a drop of water, covered with a thin glass, and examined with a power of fifty or sixty diameters. When the appearance of the plant is well impressed on the mind, remove the slide from the microscope, take off the cover glass from the object, and with a piece of blotting-paper drain off

(not blot up) as much of the water as possible. Now cover the conferva with some strong glycerine, replace the cover quickly, and examine without loss of time under the microscope, and notice the change that has taken place. The fluid contents of the conferva cells have suddenly emptied themselves into the surrounding glycerine, leaving the whole plant in a shrivelled and contracted state; in many cases the cells will be found to be ruptured, but those which have escaped injury will after a time expand and resume their natural appearance. In observing, advantage is sometimes taken of induced endosmosis, the tissues ruptured by this means often revealing points of structural detail difficult or impossible of demonstration by dissection. Endosmotic action may be prevented by introducing objects which contain light fluids very gradually into denser ones; for instance, an object should be passed from water into weak glycerine and then after a time into stronger, till at last it might be placed in glycerine of full strength without any contraction taking place. The same phenomenon takes place if marine plants are immersed in fresh water. This may be familiar to some who have attempted to wash delicate sea weeds, such as *Griffithsia setacea*, in fresh water, the result being that the cells burst and stain the mounting paper; this may be prevented by washing in sea water, or water having gum or sugar dissolved in it, so that its specific gravity approaches that of sea water. An ingenious application of the principle of gradually increasing the specific gravity

of the mounting fluid with a view to the prevention of endosmosis, will be found in the method known as Hantzsch's. The fluid consists of three parts alcohol, two of distilled water, and one of glycerine (Price's), all by measure. This medium is principally employed in mounting *Algæ.* The specimen is placed in the cell with this fluid and the cover put on, but not cemented, so as to allow evaporation to take place; the waste is supplied from time to time, until at last the cell contains nearly pure glycerine; it is then to be cemented as before described. The fluid is of very nearly the same specific gravity as water, so little or no endosmotic action takes place on the immersion of the specimen; and as the evaporation process increases the strength of the solution very gradually, the most delicate tissues can be eventually mounted in strong glycerine; doubtless this principle would answer equally well with a solution of chloride of calcium, a very valuable medium for certain preparations. Much valuable information respecting the collection and preparation of *Algæ*, will be found in "The Collector's Handy Book of Algæ," by Rev. W. W. Spicer, from which the above process is taken.

Taking the preservative fluids in groups, the simplest consist of water, either alone or in combination with some antiseptic substances.

Distilled water alone is capable of preserving such objects as the *Desmidiæ* and other *Algæ* in tolerable perfection as to form, although with more or less loss of colour and alteration of the disposition of the endochrome or cell contents. Confervæ are very apt

to grow in slides in which distilled water is used; this is best prevented by saturating the water with camphor or creosote.

Camphor water is made by placing a lump of camphor in a bottle of distilled water, and allowing it to remain a few days; the water will then be found to smell very strongly, although the quantity dissolved is exceedingly small. Such portion as may be required for use is to be filtered and kept in a small bottle; the store bottle is to be filled up from time to time with distilled water. This fluid may be used with advantage in making and diluting all the preservative fluids mentioned in these papers instead of pure distilled water, unless an indication to the contrary is given in the formula. It is capable of preserving animal tissues as well as vegetable, but with the fault of most watery liquids, that it is apt in time to induce a granulous texture in objects of this kind mounted in it.

Creosote water is made in a nearly similar manner; a few drops of creosote are poured on a quantity of precipitated chalk, and the whole shaken up in a bottle of distilled water. When the chalk has settled, the clear liquid may be poured off and filtered as required for use; the preservative properties of this and also of a very diluted solution of carbolic acid closely resemble those of camphor water. For another use of carbolic acid see paper by Dr. Bastian, *Monthly Microscopical Journal*, vol. i., p. 96.

Alcohol, diluted with water in various proportions, is much used for the preservation of large anatomical

specimens; portions of injected tissue to be viewed as opaque objects keep very well in it, also vegetable structures where loss of colour is not objectionable. The striated structure of muscular fibre is well shown when this medium is employed; a piece of cooked meat will do to experiment upon. The fibres should be well separated with the needles before the cell is closed. Many other preparations are used for the preservation of objects.

Thwaites's Fluid.—Water, 16 ozs.; alcohol, 1 oz.; creosote and chalk, as in creosote water. Pour the creosote on the chalk as before, add the alcohol, stir up the whole, and add the water very gradually; allow the mixture to stand a few days, and then filter. Dr. Beale found that this solution was liable to become thick after a time, and gives the following substitute in his "How to Work with the Microscope:"—"Creosote, 3 drachms; wood naphtha, 6 ounces; distilled water, 64 ounces; chalk, as much as may be necessary. Mix first the naphtha and creosote; then add as much prepared chalk as may be sufficient to form a smooth, thick paste; afterwards add very gradually a small quantity of the water, which must be well mixed with the other ingredients in a mortar. Add two or three small lumps of camphor, and allow the mixture to stand in a lightly-covered vessel for a fortnight or three weeks, with occasional stirring. The almost clear supernatant fluid may then be poured off and filtered if necessary; it should be kept in well corked or stoppered bottles." Dr. Beale states that he has had large preparations preserved in this fluid for

more than twelve years, and that it is still bright and colourless.

Fluids are filtered by being strained through a conical bag made of a circular piece of porous paper manufactured for the purpose, folded in the usual manner, and supported in a glass or porcelain funnel of suitable dimensions. If the proper filtering paper is not at hand, white blotting paper will answer the purpose.

Chloride of Calcium (a saturated solution in camphor water).—For making this solution, the pure fused salt should be used, and not the common kind used for drying; it should be carefully filtered before use; it can be diluted to any extent with camphor water. The saturated solution is an extremely valuable preservative fluid; it soaks into objects, rendering them transparent, but rather less so than strong glycerine; it has the advantage, also, of not injuring calcareous tissues. Insects, viz., fleas and lice, mounted whole in this medium, with little or no compression, show the tracheal system and many of the internal organs remarkably well when properly illuminated, and are still in perfect condition; date of mounting, 1866. Flax, hemp, and other similar fibres display their structure far better in this than in any other medium, the secondary deposits being very clearly brought out.

Diluted Solution.—One part of saturated solution to ten of camphor water answers well for the preservation of the fresh-water *Algæ*; the green colour is better preserved by it than it is in any other fluid.

Chloride of Sodium (common table salt).—A saturated solution seems to preserve *Entomostraca* very well indeed; it induces a slight degree of opacity, which is sometimes an advantage. Specimens of *Daphnia pulex* (water fleas) mounted in it in September, 1866, show much of the internal structure; the eyes and bundle of optic nerves are in very perfect condition. This solution is of value from its being readily procured anywhere, and a supply of specimens which would otherwise be lost may be preserved in it. Sea water impregnated with camphor or creosote will preserve various delicate marine animals and plants extremely well and without injury from endosmosis; by taking proper precautions they may be gradually transferred, if necessary, to strong glycerine.

Solution of *arsenious acid* in water has been used both alone and in combination with glycerine for the preservation of objects; the latter mixture has answered very well in re-mounting a series of injected preparations, which are now, after a period of about six years, in perfect condition. The quantity of arsenic capable of being dissolved in water is extremely small; solutions of arsenic, unless saturated with camphor, are especially liable to confervoid growths, a rather unexpected phenomenon in so poisonous a fluid.

Many other saline solutions will be found in microscopical works. The best have been given above; a larger selection would tend rather to confuse than assist the beginner.

Glycerine is one of the most valuable materials

ever added to the resources of the microscopist. We are indebted to the late Mr. Robert Warington for the application of this fluid to microscopical purposes. It is obtained as a waste product in the manufacture of soap, and lead plaster. The quality of the glycerine from these sources is very inferior, being both weak and impure. The best is that made by Price's Patent Candle Company, and obtained by a distillation process. This is much purer and stronger than the common kind, having a specific gravity of about 1240, and is the only kind fit for use by the microscopist. The properties of glycerine as a means of giving transparency to an object have already been mentioned. It is a thick, syrupy, and highly refractive fluid, nearly colourless, and intensely but pleasantly sweet. Although made from fat, it is not at all greasy, but freely miscible with water and many other fluids; it is also a solvent for a great number of substances. Its action upon varnish has already been alluded to. It is stated by Dr. Carpenter that it dissolves carbonate of lime readily, and quite destroyed the calcareous skeleton of certain *Echinodermata* mounted in it. He suggests that, when used for such purposes, it should be saturated with carbonate of lime by being kept in a bottle with some fragments of marble ("Microscope and its Revelations," fourth edition, p. 222). One of the advantages of glycerine is that it never dries; so that an object can be placed in it, covered with a glass, and left uncemented, without fear of evaporation for any length of time, and after-

wards mounted permanently, if desired. Owing to its free miscibility with other substances, it forms many very valuable compounds, some of which will presently be described. A very full account of its use in delicate physiological investigations is given in Dr. Beale's "How to Work with the Microscope," a book of the greatest service to all intending to study the particular subjects upon which it treats. It is by the use of glycerine that Dr. Beale has succeeded in carrying on his elaborate investigations of the ultimate structure of nerve tissue under excessively high powers; and his processes afford a remarkable illustration of the support afforded to a delicate tissue by immersion in a fluid of extreme density, the manipulation of tender substances being comparatively easy in glycerine, when, in water or alcohol, it would have been impossible.

Strong glycerine preserves nearly every kind of object, whether animal or vegetable, with great perfection, and is, perhaps, the nearest approach to an universal mounting-fluid yet known. Insects and other objects may be put into a bottle of glycerine, and left until wanted; they are even better after a year or two's soaking. Objects mounted in glycerine generally improve after a time, details often being visible which were not seen immediately after mounting. The introduction of the binocular microscope has very much influenced the style of mounting objects to be viewed with low and medium powers. For this purpose, it will be found advantageous to mount the object with little or no compression. Of

course, for examination with high powers, thin and compressed specimens are absolutely necessary (see author's paper, *Monthly Microscopical Journal*, vol. i., p. 331).

Glycerine can be diluted to any extent, either with camphor or creosote water, should it be desired to obtain a less refractive fluid, and one which does not render objects so transparent as pure glycerine; sometimes a portion of alcohol may be added with advantage. This compounding of media is one of the greatest arts in fluid mounting, and can only be acquired by experience, as, at present, no definite directions can be given. Diluted fluids, as a general rule, make animal tissues more granulous and opaque after a time than the strong, dense ones. The author possesses an instance of a difficult mounting accomplished almost by chance. The subject was the Medusoid embryo of *Hydra tuba*, which he had been observing at a friend's house. Thinking it a pity to lose a specimen then seen for the first time, he took the object home alive in its cell of sea-water, and then determined to attempt its permanent preservation. The course of operation was as follows:—The slide was placed in a saucer, which was quickly filled with strong alcohol (about 60 over proof). This fortunately killed the animal so suddenly that it was but little contracted. A mounting-fluid, consisting of glycerine, alcohol, and sea-water, was then extemporised, and the object mounted. It is still in good preservation, although somewhat opaque. It was mounted in February, 1862. This

is given as an instance of the kind of practice occasionally needed in cases of emergency, and where the tact acquired by experience may be turned to good account.

It is occasionally convenient to make use of a medium which, while it is fluid at the time the object is mounted, will ultimately harden, and preserve the object from injury from being shaken or moved. Such media are especially useful for mounting *Diatomaceæ* attached to other *Algæ*. There are many compounds of this nature, some of the best of which are largely composed of glycerine.

The earliest of these was that known as *Deane's gelatine*. It is composed of—Gelatine, 1 oz.; water, 4 ozs.; honey, 5 ozs.; creosote, 6 drops; alcohol, ½ oz. The gelatine is to be soaked in the water until quite soft; the honey, heated to the boiling point, is to be added. The whole is then to be boiled, and, when it has cooled a little, the creosote and alcohol, mixed together, are to be added, and the whole filtered through fine flannel.

Glycerine jelly consists of gelatine soaked in camphor-water until it swells and becomes soft. The surplus water is to be poured off, the gelatine melted in a water-bath (a large wide-mouthed bottle placed in a saucepan of hot water will answer the purpose), and the resulting jelly strained, and, if necessary, clarified after the manner of confectioners with white of egg. To every ounce by measure of this jelly add 1 drachm of alcohol and 6 drachms of Price's glycerine.

Both these media are used by melting the composition by placing the bottle in hot water, just as glue is melted. It is then used almost precisely in the same way as Canada balsam, taking the precaution to prepare the object by a previous soaking. Thin objects do not require a cell When the gelatine has hardened sufficiently, the surplus portion is scraped off, and the slide cleaned. It should then be secured with a coat or two of liquid glue, followed by several coats of gold-size, as in moist preparations.

A very useful medium of nearly similar properties is made according to the following formula of Mr. Farrants :—Picked gum arabic, 4 parts by weight; water, 4 parts ; glycerine, 2 parts. The mixture is to be made cold, and, if necessary, strained through fine muslin. It is to be used in the same manner as the foregoing gelatinous preparations, only without heat; which renders it particularly fit for objects that will not bear the slight increase of temperature required to liquefy gelatine.

The action of all the above media is nearly similar to that of slightly diluted glycerine, excepting that, when set, they keep the object fixed in the position in which it was mounted. It is necessary when using these preparations to guard against endosmotic action, by soaking in suitable fluids.

Strong syrup is capable of preserving animal and vegetable tissues, but is, under some conditions, liable to crystallise. The best proof of the perfect manner in which vegetable substances are preserved is given in the condition of preserved fruits, which are in

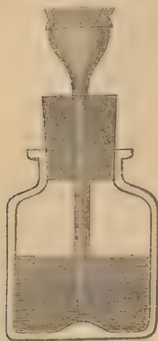
an extremely favourable state for microscopical examination. The samples of jam, &c., examined by Dr. Hassall, and reported upon in his "Food and its Adulterations," were probably among the tissues most easily identified, owing to their perfect condition.

Castor-oil will be found an excellent mounting-fluid; it penetrates, and gives considerable transparency, and keeps the object well and for a long period. It is particularly successful with parasitic insects; these may be placed in a bottle of castor-oil, and kept until required for mounting. As castor-oil is so readily procured, being in every medicine-chest, and to be obtained at any little village shop, it is a very useful medium for those who may wish to preserve insects, &c., captured while travelling, as they need no attention after they are immersed in it. Should it be desired to mount the objects ultimately in some other medium, the oil can easily be removed by soaking in benzol.

Mounting-fluids which are in frequent use are best kept in a small, wide-mouthed bottle, through the cork of which is passed a pipette, surmounted by a funnel at its upper extremity, upon which is stretched a piece of sheet india-rubber (Fig. 18). By this contrivance, a small quantity of fluid can be taken up, and delivered, drop by drop, upon the slide. Where mounting-fluids are continually required, as in pathological laboratories, Dr. Beale has contrived a little fountain on the principle of the wash-bottle, which answers admirably for a supply of any kind

of fluid in drops; but, for the occasional use of the student, the pipette-bottle is to be preferred.

Fig. 18.



Closely connected with fluid mounting is the process of staining tissues. This is used for two widely different purposes. The first for rendering very transparent bodies more easily visible; this is easily done by immersion in magenta, diluted as the particular case may require. The other for more clearly defining portions of the tissue in a particular physiological condition; this is done by using staining fluids which act unequally. For instance, if it be desired to stain the nuclei of cells, the solution of carmine, described by Dr. Beale in "How to Work with the Microscope," and reprinted here by his kind permission, will answer admirably:—"Carmine, 10 grains; strong liquor ammoniæ, ½ drachm; Price's glycerine, 2 ozs.; distilled water, 2 ozs.; alcohol, ½ oz. The carmine, in small fragments, is to be placed in

a test-tube, and the ammonia added to it. By agitation, and with the aid of the heat of a spirit lamp, the carmine is soon dissolved. The ammoniacal solution is to be boiled for a few seconds, and then allowed to cool. After the lapse of an hour, much of the excess of ammonia will have escaped. The glycerine and water may then be added, and the whole passed through a filter, or allowed to stand for some time, and the perfectly clear supernatant fluid poured off and kept for use. This solution will keep for months, but sometimes a little carmine is deposited, owing to the escape of ammonia, in which case one or two drops of liquor ammoniæ to four ounces of solution may be added." For further information relative to the application of the staining process, and the observations to be carried out by its means, the student is referred to Dr. Beale's work.

Solutions of chloride of gold and nitrate of silver may also be employed to advantage (see paper by Dr. Bastian before quoted; T. Dwight, *Monthly Microscopical Journal*, vol. ii., p. 45).

CHAPTER V.

NEXT in importance to the possession of a good instrument, is the having a good supply of light and knowing how to make proper use of it. The sources of light available for the microscopist's use bave already been described; the ways of utilising the light so obtained, and the instrumental appliances for directing it, form the subject of this chapter.

The natural division of illuminators is into two classes—those which act above the stage of the microscope, and send light down upon an object; and those which are placed below the stage, and send light through it.

Of instruments of the first class, one—the *condensing lens*—is usually supplied with every microscope, however plainly equipped. This lens enables light to be concentrated upon the object on the stage; either a double-convex or a plano-convex lens may be used for this purpose. If the first is employed, no particular attention is required beyond placing it at such a distance above, and on one side of the stage,

that the light falls at a suitable angle, and that the object is in or near the focus; should a plano-convex lens be used, its position is of some importance, as, if it is turned the wrong way, its spherical aberration is greatly increased, and, of course, a corresponding amount of light lost. The plano-convex lens, or bull's-eye, when used to concentrate parallel rays—daylight, for instance—or divergent rays, such as those proceeding from a lamp, should always be placed with its convex side turned towards the source of light, as the spherical aberration is then much less than it would be when placed in the contrary direction; if the lens is to be used for rendering parallel the divergent rays of a lamp, then the bull's-eye is to be placed in the opposite position, with its flat side turned to the lamp, and at a distance from the flame equal to its focal length. Parallel rays are required when using some of the illuminating apparatus presently to be described.

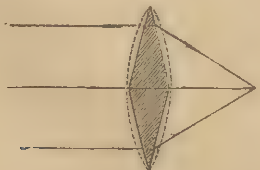
Very much may be done with the condensing lens, if skilfully used; especial care is required that it causes the light to fall on the object in the right direction, as the appearance of the surface of many substances is very different when illuminated from opposite sides; the student should, therefore, never be contented with a single observation of a strange substance, but should change its position, so that it may be viewed with the light falling upon it in as many directions as possible. This is most easily effected by causing the object to rotate while the light is directed upon it, so that the alteration caused by

every change of position can be easily noted. The necessary movement is now very generally fitted even to the stages of small instruments, and persons about to procure a microscope would do well to incur the small extra cost of this useful addition.

The light obtained by the condensing lens may be greatly augmented by using two, one of larger dimensions than the other, the light being brought to a certain degree of convergence by the first and larger lens, and afterwards concentrated by passing through the smaller one, which should be so placed as to intercept the cone of light from the large lens at the place where it is of its own diameter.

Most of the other illuminators of this class act by reflection, mirrors of various forms being employed. The optical properties of concave mirrors resemble, in many points, those of convex lenses; they cause parallel rays to converge (Fig. 19), render divergent

FIG. 19.



rays parallel, or convergent, and also form images (Fig. 20). Microscopes and telescopes can be constructed with mirrors or specula, instead of object-glasses; this principle is still in use as regards telescopes of large dimensions, as the difficulties of

making object-glasses of large diameter are very great; the largest yet accomplished is only 25 inches,

FIG. 20.

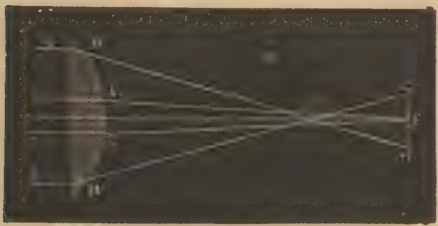
while the largest speculum (that of the late Lord Rosse) is 6 feet in diameter.

Professor Amici constructed a very efficient compound microscope, having an elliptical speculum in place of an object-glass; the plan, however, was abandoned on the introduction of the achromatic principle, although its performances were very superior to those of the non-achromatic instrument.* Concave mirrors, when formed of segments of spheres, are liable to spherical aberration, just as lenses are (Fig. 21); therefore, when it is required to render divergent rays parallel, or bring parallel rays to a focus, it is necessary that the figure of the mirror should be that of a parabola. Specula of this form are used in astronomical telescopes, the reflectors of lighthouses on the catoptric principle, and in some instruments presently to be described. The parabolic curve differs from the circle principally in being flatter at the edges and deeper at the centre. Reflecting instruments are entirely free

* One of these instruments has recently been presented to the Royal Microscopical Society; there are also several old and curious microscopes in the Society's collection.

from chromatic aberration. The oldest of the reflecting illuminators is that known, from the name of

FIG 21.



its inventor, as the *Lieberkuhn* (Fig. 22); it consists of a spherical silver mirror, perforated, to allow it to

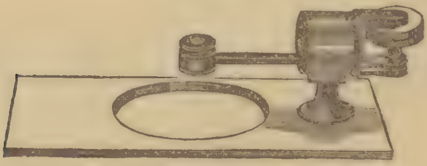
FIG. 22.

A B

slide over the setting of the object-glass, and is so adjusted that the focus of the speculum is coincident with the working distance of the object-glass. The object is illuminated by light reflected through the hole in the stage by means of the mirror; this is again reflected, but in a very convergent state, upon the object, which will be intensely illuminated if the speculum is well adjusted to focus and properly supplied with light.

It is necessary to place beneath the object a black stop of sufficient size to fill the field of the object glass, otherwise the light from beneath entering the microscope will cause a disagreeable amount of fog and indistinctness. The best kind of background consists of a dark well or little cup of proper size painted black inside, and placed below the object; a patch of black paper or paint will, however, answer the purpose. Beck's disc holder (Fig. 23) is

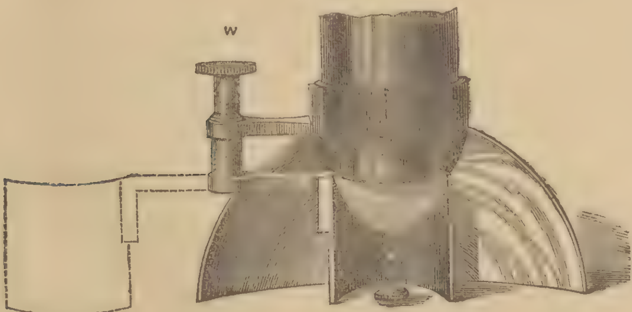
FIG. 23.



particularly useful for objects to be examined by the aid of the lieberkuhn, as it forms its own black stop. Its late talented inventor was very expert in the employment of this kind of illumination. The defects of the lieberkuhn are that its light is nearly

vertical, and therefore, like the tropical mid-day sun, casts little or no shadow; this, however, may be remedied, to some extent, by turning the mirror aside and using the light from only one-half of the speculum (Fig. 22, B); it also requires the object and its mounting to be small enough to allow the free passage of the light around it from the mirror. These defects caused the lieberkuhn to fall somewhat into disuse; the introduction of the binocular microscope, however, caused it again to be employed, as it

FIG. 24.



was found very suitable for the peculiar class of opaque objects which are so well displayed in relief by its stereoscopic power. It has, however, again been nearly superseded by an improved form, which has all its advantages, besides some peculiar to itself. This improved instrument, which is known as the *parabolic lieberkuhn* (Fig. 24), is another of the numerous contrivances of the late Richard Beck, and was described by him in the *Microscopical*

Quarterly Journal for 1865 (vol. xiii., p. 116). It consists of a portion of a silvered paraboloid, which is attached by a ring to the setting of the object-glass, so that it has some range of adjustment like the ordinary lieberkuhn; but instead of the light being directed upon it from below through the hole in the stage, it is supplied from one side, which allows this form of lieberkuhn to be used with objects mounted in the ordinary way. It is necessary when lamp light is used that the rays should be rendered parallel by placing a condensing lens between the lamp and the reflector, as before-mentioned. As there is a very large reflecting surface, and from the parabolic figure of the mirror no spherical aberration, the amount of light concentrated upon the object is much greater than could be obtained from the ordinary spherical lieberkuhn. It has also the advantage of reflecting rays from one side only, and of considerable obliquity. These properties make it the most perfect illuminator yet produced for viewing opaque objects by reflected light. Its effect is almost like that of brilliant sunshine, lighting up the interior of every cavity, and yet, at the same time, casting strong shadows and defining minute portions of structure in a manner hitherto unapproached. The paraboloid as usually constructed is adapted for use with objectives of from 2 inches to $\frac{2}{3}$ focus. An ingenious mounting, allowing a very large range of adjustment to be given to the paraboloid, has been contrived by Mr. Crouch, who uses a short adapter screwed into the body of the microscope as a support

to the reflector and its fittings; these consist of sliding tubes and ball-and-socket joints, by means of which it can be placed in extremely varied positions, and is adapted for use with any microscope or object-glass fitted with the universal screw. It must be borne in mind that these advantages are gained at the expense of removing the object-glass a small distance, viz., the length of the adapter, from the Wenham prism, while, to obtain the best possible definition, the back lens of the objective cannot approach the prism too closely; therefore in making choice between the two forms of mounting the paraboloid, the student must consider whether convenience with a trifling loss of definition will suit him, or whether the most perfect definition is required with the inconvenience attending the ordinary form.

An addition to the parabolic lieberkuhn, consisting of a small plane mirror (Fig. 24, *m*) inclined at an angle of 45°, and so fitted that it can be brought into the proper position for reflecting light vertically upon the object by means of the milled head, w, has been made by Messrs. Beck, at the suggestion of Mr. Sorby, who required this contrivance for viewing the polished surfaces of specimens of iron and steel. When light is directed obliquely upon a highly polished surface, it is reflected at an angle equal to the angle of incidence, none of it enters the microscope, and the surface appears intensely black; but when illuminated vertically, all its structural peculiarities are at once brought into view.

For such researches the plane speculum is indispensable, and its adaptation in no way interferes with the ordinary use of the paraboloid.

The late Richard Beck made a small paraboloid, adapted for use with the 4-10th objective. This the author had an opportunity of working with, and. although only in experimental condition, was much pleased with its performance. It was returned after trial, but has not at present been produced for sale by Messrs. Beck, probably on account of its value not being generally known. From its very short focus, it requires much more careful fitting to the objective it is intended to be used with than the larger paraboloid; but when carefully executed, it works quite as well with its own object-glass as the one above mentioned with the lower powers. The author, however, possesses one which was made for him by Mr. Bailey, of 162, Fenchurch Street, which performs admirably, and is executed in this optician's usual careful manner. The parabolic lieberkuhn is of great value with ¼ inch and 4-10th objectives, as these glasses allow but little space between the front glass and the object for illumination with the condensing lens.

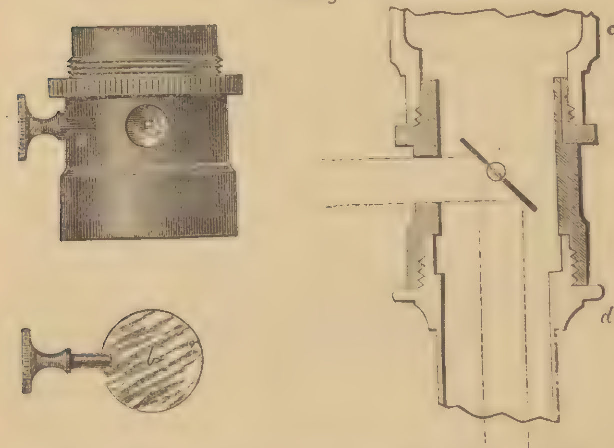
A very efficient illuminator was, until recently, much in use; it is known as the *side reflector*, and consists of an oblong silvered mirror of spherical figure. It has ball-and-socket and sliding adjustments, and is attached either to the stand of the microscope or else is mounted upon an independent support; it is placed on one side of the instrument,

and the light directed upon it from the opposite side. The speculum is then adjusted until the object is properly illuminated. It has, however, been superseded by the parabolic lieberkuhn before described.

A means of illumination adapted for use with objectives of high power, in which the space above the object is too small to admit of light being thrown upon it by any of the apparatus just described, has been contrived by Professor H. L. Smith, of Kenyon College, Ohio. He uses the object-glass itself as a condenser. A pencil of light is admitted through an aperture in the side of an adapter screwed on to the body of the microscope, which contains a small silvered mirror with suitable adjustments for reflecting the pencil downwards through the object-glass which is attached below the adapter. This apparatus was sent to Mr. E. G. Lobb, of the Royal Microscopical Society, and exhibited at the meeting in January, 1866. The instrument was placed in the hands of Messrs. R. and J. Beck and Messrs. Powell and Lealand, who each produced an improved modification. For the silvered mirror of Professor Smith they both substituted an unsilvered glass surface; that of Messrs. Powell and Lealand was a piece of parallel surfaced glass, fixed at an angle of 45°; Messrs. Beck used a disc of thin cover glass (Fig. 25, *b*), and allowed the angle to be altered at pleasure by means of a milled head, *f*, passing through the aperture, *e*. The light of a lamp is directed through the hole, *a*, in the adapter, and forms an image of the flame on the object when the object-glass is in focus. The lamp

should be placed at a distance of about eight inches from the instrument; sometimes a condensing lens may be placed between the lamp and microscope with advantage. The manipulation with the instruments of

FIG. 25.

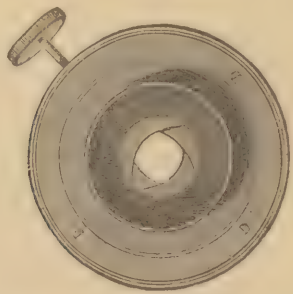


both makers is precisely similar. The objects to be viewed with this illuminator should be uncovered, otherwise the cover reflects nearly the whole of the light, and scarcely any falls upon the object; some light is also lost by reflection on its passage upwards through the oblique unsilvered mirror. The impossibility of obtaining a satisfactory view of a covered object will most probably prevent this instrument from coming into very general use, although it affords valuable information to those who will take the trouble to master the difficulties attending its use.

The second class of illuminators, those which are placed beneath the stage, are also very numerous. The most familiar is the *mirror*, which forms a part of every microscope. A great variety of illumination may be obtained from the mirror alone, if properly mounted so that it may be turned considerably aside. The mirror of many microscopes is now placed on a double-jointed arm, which permits very oblique illumination to be obtained. In order to understand practically the difference caused by the position of the mirror, the student is recommended to examine a diatom of moderate difficulty, such as *Pleurosigma angulatum*, with a good $\frac{1}{4}$ or $\frac{1}{5}$ objective, which should be accurately adjusted for the thickness of the cover glass, and used with a deep eye-piece. It will be found, when the light is central, that none of the usual markings will be visible; but when the illuminating pencil falls very obliquely, the *apparent* cross lines (?) will come into view. With the better class of microscopes, the mirror is usually made double, one side concave and the other plane; the plane mirror is used for reflecting daylight when the greatest intensity is not required, and for use with the achromatic condenser and parabolic reflector (Wenham's), and in all other cases when parallel rays are needed. The concave mirror acts in some degree as a condenser, and is to be used with lamp light or when it is required to make daylight more intense. The *diaphragm plate* is used in combination with the mirror to regulate the angle of the pencil; this can, however, be done with

much greater nicety by employing the graduating diaphragm of Mr. Collins (Fig. 26) or the very beau-

FIG. 26.



tiful iris diaphragm of Messrs. Beck (Fig. 27), both of which allow the aperture under the stage to be gradually diminished or enlarged without the interval

FIG. 27.

of darkness which occurs during the shifting of the ordinary wheel of diaphragms.

A very useful illumination, resembling the light of a *white cloud*, may be obtained by placing a piece of white paper over the mirror, and concentrating the light of a lamp upon it by means of the condensing lens. The soft white light so produced is extremely pleasant to use, and suits delicate and

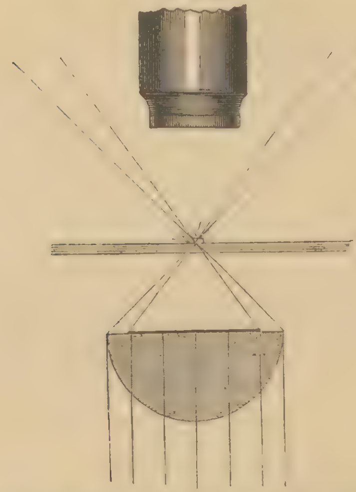
transparent objects viewed with the binocular, and will be found of more general service than the full light of the mirror, which, with the double body, often produces a most disagreeable glare, which only obscures and confuses instead of defining.

The mirror affords the simplest means of obtaining what is known as *dark field illumination*, for which we are indebted to the Rev. J. B. Reade, F.R.S., President of the Royal Microscopical Society. His original contrivance consisted of an ordinary condensing lens, so placed with respect to the lamp and the stage, that it transmitted a pencil of such obliquity that none of it entered the object-glass, so that the object alone was lighted, while the field remained dark. The same effect can be produced with the mirror when turned very much aside, and only a low power, such as an inch or ⅔ objective, employed. It is a most valuable mode of illumination, and one which the author employs very extensively, as independently of the beautiful effects produced by it when skilfully managed, it enables structural peculiarities to be observed which are not readily demonstrated by other means.

The black field is still more perfectly obtained by the use of the *spotted lens* (Fig. 28). This consists of a small bull's-eye, mounted so that it will slide up and down in a fitting beneath the stage to allow of focussing; on the centre of the plane side of the lens is placed an opaque black stop, allowing only the marginal rays to pass. If an object is placed in the focus of the hollow cone of light so transmitted, it

will be found, if possessing sufficient opacity, to disperse a portion of the light, to shine brilliantly, and become apparently self-luminous; while, as will be seen by the diagram, the rays, after

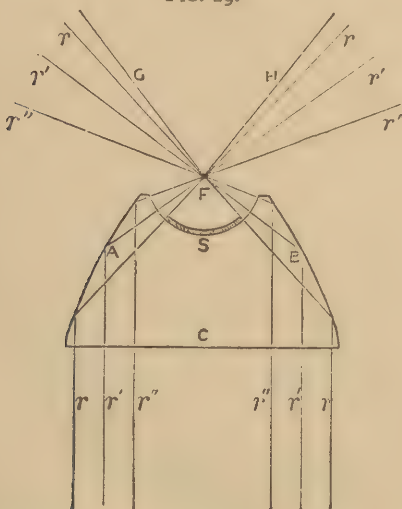
FIG. 28.



crossing at the focus, diverge, and do not enter the object-glass, and so leave the field more or less black. The effect is very much that of causing a semitransparent object to appear like an opaque one illuminated by reflected light. *Diatomaceæ*, living aquatic animals and plants, the skeletons of the *Polyzoa*, insect preparations when not too thin and transparent, and many other objects, are displayed to the greatest advantage by means of black field illumination.

Black field illumination is obtained most perfectly by means of a *paraboloid* placed beneath the stage. Mr. Wenham's first contrivance consisted of a silvered parabolic cup, open at the apex, which reflected parallel rays very obliquely, the access of direct light being prevented by a stop placed in a proper position. The performance of this illuminator was perfect, the

FIG. 29.



only objection to it being that it was rather difficult to keep the reflecting surface bright. This has been remedied by constructing the paraboloid of glass, the illuminator now in use being a solid cast in glass of the original silvered speculum (Fig. 29). It reflects light quite as well as if it were silvered, owing to the

law of internal reflection. When a ray of light passing through glass falls upon a surface the angle of which is not less than 38° 41′, it cannot pass out of the glass into air, but is totally reflected (Fig. 30).

FIG. 30.

The ray, *a*, entering the triangular prism at *b*, passes through to *c*, where not being able to pass out into air, it is reflected as if the surface at *c* were silvered, only far more perfectly, the reflection being total. This principle is made extensive use of in the construction of optical apparatus, a reflecting prism being always preferable when it can be used, on account of its wasting less light than a metallic speculum or silvered glass mirror. If a tumbler is filled with water, and the surface of the water looked at upwards through the side of the glass, it will be found that the surface of the water will reflect light more brilliantly than the best mirror. The glass paraboloid, although unsilvered, and appearing at first sight to be a lens rather than a mirror, is nevertheless a far more perfect reflector than its metallic predecessor. Parallel rays (Fig. 29, *r*, *r′*, *r″*), falling upon the plane surface, c, at right angles, enter the glass paraboloid without refraction, and, not being

able to pass out through its curved sides, A, B, are reflected to the focus, F, and diverge from thence at an angle so great that none of them enter the object-glass. The apex is ground out to a spherical figure, so that the pencil also emerges without refraction. The centre stop, S, is attached to a wire passing through a hole drilled in the block of glass, and furnishes a means of adjustment, so that the least oblique rays can be cut off if required, which is necessary when the paraboloid is used with the higher powers, the stop in that case being pushed up as far as it will go. A well constructed paraboloid is capable of giving a black field with a $\frac{1}{8}$th of 100° of aperture. The paraboloid is superior to the spotted lens on account of its freedom from chromatic and spherical aberration, and also from its larger angle, which is about 127°, while the angle of the spotted lens is a little under 90°. The spotted lens, however, can be used with advantage in examining objects which have a degree of transparency which would prevent their perfect observation with the paraboloid, this latter illuminator being better suited for the examination of semi-opaque or translucent tissues. Black field illumination, like that by reflected light, is perhaps more free from the deceptive appearances which so frequently lead to errors of interpretation, and one or both of these modes of lighting should always be employed when practicable. As the amount of light stopped by the object depends in some degree upon its opacity, the relative density of the various parts may be fairly judged of by their

respective brilliancy. Dark field illuminators aid very much in the production of stereoscopic effect, no methods of illumination, save those by reflected light, giving such correct views of the relative position in depth of the various parts of an object, with an advantage peculiar to themselves of revealing internal structure to a great extent.

In the old microscopes, constructed before the introduction of the achromatic principle, the want of light was very evident when any but the lowest powers were used; this soon led to the employment of some means of increasing the intensity of the illumination. The usual plan was to place a lens beneath the stage, which acted like a burning-glass, and allowed the light to be increased to almost any extent. When the microscopic object-glass was freed from the chromatic and spherical aberrations, the increase of illumination following the enlargement of its angle of aperture for a time satisfied observers; soon, however, a larger amount of light was, in some cases, found desirable, and it was usual to employ one of the object-glasses (generally the next lowest to the one in use) to concentrate the light upon the object. This simple contrivance is very effective when nothing else but greater intensity is needed, and a foreign ¼ object-glass will make a very good combination for this purpose when suitably mounted. For the next improvement, we are indebted to Mr. Gillett, who added a series of diaphragms; these, in the most improved form, comprised some having marginal as well as central

apertures, as it was soon found that the direction of the light had a very important influence. The condenser has since undergone many improvements, each of the three leading opticians modifying it to suit the requirements of their respective instruments. It consists, as now made, essentially of a combination of achromatic lenses closely resembling an object-glass, and fitted with one or more diaphragm plates, which, either separately or in combination, give perfect control over the amount of light admitted and its direction; the details of construction vary somewhat in different condensers. This is mounted beneath the stage of the microscope with suitable adjustments for focussing, and also for placing it truly in the axis of the instrument, or centering. As the instrument is difficult for the beginner to use, it is well to give a few directions.

The first care will be to centre the condenser, as the spot of concentrated light is extremely small, and, should the adjustment not be accurately made, the field of the microscope will be only partially, or not at all, illuminated. The simplest way of centering is to screw on a very low power, and view the setting of the top lens of the condenser; it will then be readily seen whether it occupies the centre of the field, and, should it not do so, the requisite traversing screws are moved until it is found to be accurately in the centre. Or the image of a lamp-flame may be formed with the condenser, and viewed with a moderately-low power, and the screws moved until the image occupies the centre of the field. The focus is then

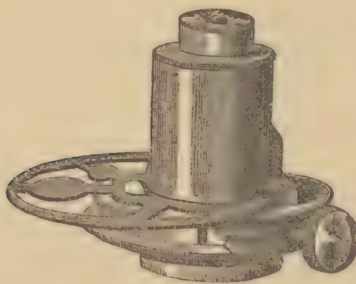
to be adjusted by moving the milled head connected with the proper rack, and a suitable diaphragm turned into place. When the achromatic condenser is used, the flat mirror is to be employed, and if a lamp is the source of light, the rays must be rendered parallel, as before mentioned. Some observers use a prism in the place of a mirror, as it reflects more light, and of a purer quality, than silvered glass; this gives a reflection from its upper as well as its silvered lower surface, which somewhat interferes with the perfect illumination of delicate objects. Although the most intense light is obtained when the condenser is accurately in focus, it is sometimes preferable to use the condenser either a little within or beyond the focus; for this, as well as the choice of diaphragms, no particular directions can be given, as much depends upon the nature of the object to be viewed, construction of the instrument, and many other circumstances. A little practice, with the help, if attainable, of an experienced microscopist, will be found the best means of mastering the use of this rather difficult instrument. It is an instructive exercise to place a suitable object upon the stage—a Diatom, for instance—and notice the changes in appearance produced by altering the focus of the condenser and using different diaphragms; so varied are the kinds of marking produced on some of the *Diatomaceæ* by changes of illumination, that it would hardly be believed that the object was the same. It is now tolerably certain that the striæ, or lines, whether single or crossed, and the dots, seen on some of these

objects, are non-existent, being merely the optical rendering of closely-packed transparent hemispheres. These were observed some years ago by Mr. Wenham, with a 1-50th objective of his own construction, and quite recently by a new and comparatively simple means of illumination discovered by the Rev. J. B. Reade, and described by him in the *Monthly Microscopical Journal* (1869, vol. ii., p. 5). The instrument used is an equilateral triangular prism, which is so adjusted as to reflect an oblique beam of parallel rays. With this illumination, the hemispheres on *Pleurosigma formosum* may be seen with a power as low as a $\frac{2}{3}$, provided the angle of aperture be sufficient. This simple illuminator may probably be of great value for other purposes, besides viewing the surfaces of *Diatomaceæ* ; at present, however, it has been so short a time in use, that its full capabilities have not been tested.

More recently, a condenser, constructed on a different principle, has been introduced, the optical portion closely resembling the Kellner eye-piece, instead of following the usual pattern, which is derived from the object-glass. This condenser (Fig. 31), now well-known as the "Webster," is a most efficient instrument, and, from the simplicity of its construction, is capable of being adapted with advantage to small microscopes. The amount of light given by it is considerable, so great that with the full aperture it is almost more than the eye can bear; this excess of light, if it can be considered as a fault, is certainly a good one, as it permits a very extensive use to be made

of diaphragms. The graduating diaphragm (Fig. 32) can be applied to the Webster condenser with the greatest advantage, and its effect is much more

FIG. 31.



marked than when merely used below the stage to control the illuminating pencil from the mirror.

FIG. 32.

The wheel above the graduating diaphragm consists of a series of central and lateral stops, by the use of

which a great variety of oblique dark and field illumination can be obtained; the latter far more efficiently than by the use of the ordinary spotted lens. Recently, a revolving carrier for additional diaphragms has been added to this condenser. It consists of a tube sliding into the lower part, provided at its upper extremity with a contrivance for holding a disc of card or thin brass, in which one or more apertures may be cut. By turning the diaphragm-holder round, the oblique pencil may be directed from any azimuth, and the effect on such objects as the *Diatomaceæ* is very marked indeed, the striæ appearing and disappearing as the aperture is moved to, or away from, the proper angle for bringing them out. This contrivance also allows the observer to try any forms of stop he may consider advantageous, as they may be quickly cut out of a piece of blackened card (B. W. Richardson, *Quarterly Microscopical Journal*, vol. vi., pp. 10, 86). The long focus and large field of the "Webster" render it particularly useful for the general purposes of the student, as it will work into some depth of water, and can be used for illuminating the interior of the troughs so frequently employed in observing living aquatic animals and plants. Although surpassed by the more costly instruments for the most refined description of illumination, it possesses merits peculiarly its own, and no single piece of apparatus can be made to perform so great a variety of offices as this very useful condenser.

The most useful forms of illuminating apparatus

have now been described; there are many others, chiefly meant for special purposes—they will be found in the works of Quekett and Carpenter, and the pages of the *Microscopical Quarterly* and *Monthly Journals*, to which the student is referred for descriptions and figures.

CHAPTER VI.

IN the modes of illumination hitherto described, the light has been made use of in exactly the same condition in which it was received from its source, whether from the sun or a lamp. All that instruments have been required to do has been either to alter its direction or, by concentration, to increase its intensity. It is now proposed to explain a method of conducting microscopical investigations in which the properties of the light have undergone such changes as to produce effects totally different from those of ordinary illumination, and with the result of giving greater insight into the nature of certain structures than could be obtained by other means. The light, in the condition now to be described, is commonly known as *Polarised light.*

With a view to simplify the matter contained in the foregoing chapters, no more has been said about the nature and properties of light than was absolutely necessary to enable the action of the apparatus

described from time to time to be tolerably well understood. And, although, in the present chapter, far more notice must be taken of the subject, it is by no means intended to give an exhaustive account of the phenomena of polarised light. Space can only be afforded for such an outline as will enable the student to use his apparatus, and observe intelligently. For details, reference must be made to works treating more fully on the subject—such as the chapters on Optics in Mr. Brooke's "Manual of Natural Philosophy," and the various authorities there referred to.

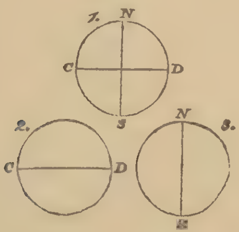
Light, in common with the other forces of nature—heat, electricity in its various forms, dynamic force, &c.,—proceeds from its source in a series of undulations or waves, which may be illustrated in a rough manner by throwing a stone into a pond, when the waves will be seen to spread themselves concentrically from the source of motion.

For convenience of explanation, a ray of light in its ordinary condition may be represented in ideal section by a circle (Fig. 33, 1), and undulations supposed to take place in two planes at right angles to each other (C, D and N, S). By means presently to be described, these two sets of waves can be separated, as at 2, C, D and 3, N, S. The ray of light, instead of having the same properties on every side, will be found to have acquired some qualities peculiar to the state in which it now is, and which may be named the properties of sides. For instance, 2 will exhibit certain phenomena in the direction C, D which do not

exist when it is examined in other directions. The same is the case with the other half of the ray (3), which exhibits similar phenomena in the direction N, S. As these properties somewhat resembled those of the poles of a magnet, the term *polarised light* was used to distinguish light so modified, and, although perhaps not the best name that could have been given, has still been retained.

As the phenomena of interference will be frequently mentioned, it will be desirable to state what they are. The sensation affecting the optic nerve which is

FIG. 33.



known as light is caused by the undulations before spoken of—light being represented by motion, darkness by rest.

Should two waves start together from the same place, they would increase each other's intensity; the result would be a wave of double height—a matter easy of comprehension, if water be considered as the medium; with the waves of air producing sound, the result would be a louder sound; and, with light, an illumination of double intensity.

Should, however, one wave start before the other by the length of half a wave, the effect would be that the crest of one wave would occupy the position of the hollow of the other, and so fill it up, producing a dead level. The result would be, with water, calm; with air, silence; with light, darkness.

This is known to be the case, in some instances, where the streams from two channels meet in the manner just mentioned: perfectly smooth water is produced, although, before meeting, the surface of both may be violently agitated.

Should the waves of light start at an interval of less than half a wave, they will, by interference, be broken up into smaller waves, the magnitude of which depends upon the distance one wave has had the start of the other. These small waves produce coloured light, the red wave being the longest, and the violet the shortest. Mr. Woodward gives the following as the lengths of the waves of the various coloured rays of the spectrum:—Red, 266; orange, 240; yellow, 227; green, 211; blue, 196; indigo, 185; violet, 167. The figures represent the numerators of fractions, having as a common denominator the ten-millionth of an inch.

These coloured waves may be produced in various ways; for instance, by very thin plates of transparent substances, such as mica, films of oil or varnish floating on water, and films of air enclosed between transparent solid surfaces; which, by causing a slight difference in the distance of the starting points of the two series of waves of white light reflected

from the upper and lower surfaces of the film, set up interference, and break up the waves of white light into smaller coloured ones. The films of varnish were very ingeniously taken up from the surface of water on enamelled cards, by Mr. De la Rue, giving them a beautiful iridescent appearance. Other examples may be found in the feathers of certain birds, as humming birds, peacocks, &c., which possess a metallic lustre produced in the same manner. A minutely grooved surface will also produce similar effects; for example, mother-of-pearl, which consists of a series of thin plates of shell, separated by folds of membrane, producing a grooved structure; also in the finely-ruled gold ornaments known as "Barton's buttons," and the minute specimens of ruling on glass by Nobert, all of which produce brilliant metallic tints by the interference of the two waves reflected, one from the surface, and the other from the bottom of the groove.

If a convex lens of extremely shallow curvature be placed upon a plane glass surface, and an arrangement be provided for exercising delicate and uniform compression, a series of circular concentric coloured bands will be seen; these are known as "Newton's rings," and are caused, as before, by the interference of the reflections from the film of air contained between the lenses; and as, from the curvature of the lens, the film is of a thickness increasing from the centre to the circumference, a variety of tints are formed at every change of thickness, the rings consisting alternately of groups of colour and dark

bands, the latter being the places where total interference takes place, and darkness or rest is the consequence. These dark spaces are much better seen when the apparatus is viewed by a monochromatic light, such as that produced by the flame of a large spirit-lamp the wick of which has been sprinkled with common table-salt. Not only will the dark bands be sharper and more intense, but they will also be considerably increased in number. These rings may often be seen when plane glass surfaces are unequally compressed; for example, a piece of thin cover-glass pressed on a slide with a stick, and sometimes between the thick plate and glass negative in a photographic printing frame.

The undulatory motion of light would seem to be expressed with considerable clearness in the first chapter of Genesis when read in the original Hebrew, which, in common with the other languages of the same family, is remarkable for the numerous inflexions of its verb, which gives it a delicacy and precision of expression unattainable in Western languages. The first verse concludes:—"And the Spirit of God *moved* upon the face of the waters." This sentence immediately precedes the command that light, which may here be taken in its largest sense, including electricity and the other forces, should exist. The Hebrew word translated "moved" is more accurately expressed by *fluttered*; the same inflexion of the verb is used in this sense in the only other place in which it occurs, viz., Deuteronomy xxxii., 11., where it refers to the fluttering of an eagle over its nest. It is

certainly a very remarkable expression, and the author believes that its bearing on the subject of light has hitherto escaped notice. The view that the word "light" includes the other forces, and which we have every reason to believe are but different manifestations of them, is supported by the fact, that sources of light proper, or luminaries, are not mentioned until the fourteenth verse, while the atmosphere or "firmament" of the English version, land, and water, and vegetable life, were all in existence, and under the influence of these mysterious powers of nature, respecting which the undiscovered and unknown probably far exceeds the little that science has at present made us acquainted with.

Light may be polarised in several ways. If a ray of light falls upon glass at an angle of 56° 45′, one-half (Fig. 34) will be transmitted, the other half reflected; and, if, instead of a single plate, about ten sheets of thin window-glass be employed, the result will be much more perfect. The reflection, whether one or more plates be used, will be much improved by either coating the back with black-varnish, or placing in contact with it a piece of black cloth or velvet, which will absorb the transmitted portion of the ray. If the light so reflected be examined by another glass mirror, placed at the same angle, and so mounted that it can be moved horizontally in a circular direction, it will be found that, in some positions, the light will be reflected, while, at others, it will pass through, or be absorbed if the back is blackened. These intervals of reflection and transmis-

sion occur alternately at every quarter revolution of the upper mirror or analyser, corresponding with the points in Fig. 33, I, marked C, D and N, S.

If a ray of light be passed through a crystal of Iceland spar, one portion will be refracted according to

FIG. 34.

the usual law (*ante*, p. 5); the other half will be refracted in a different direction. And if these two rays of light be examined with an analyser, they will be found, as in the case of the reflected light, to have acquired the property of sides, or to be polarised. The ray refracted in the common way is known as the ordinary ray; the other, which is polarised in a plane at right angles to it, is termed the extraordinary ray. If a crystal of Iceland spar be placed on a sheet of paper having a black spot on it, the double refraction

will cause the formation of two images of the spot or other device drawn on the paper.

By an ingenious process, invented by Mr. Nicol, a crystal of Iceland spar is divided in the direction indicated in Fig. 35, and joined together again with

FIG. 35.

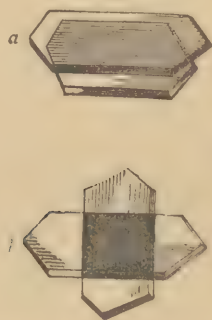
Canada balsam. This causes one of the rays to be so much refracted that it is thrown altogether out of view, and only one polarised ray is transmitted. This contrivance is known as the *single image* or *Nicol prism*, and is the means of polarisation most generally adopted for microscopical purposes.

Polarisation may also be effected by the use of thin slices of a mineral known as *tourmaline*. This mineral, when cut into thin plates parallel to the axis of the crystal, allows only the undulations in one plane to pass, the other being stopped. The cause of this action is, as yet, not understood. If two plates of tourmaline are superposed, and held before a strong light, it will be found that the light is alternately transmitted and stopped at every 90°, when one of the plates is rotated.

The same effect is produced, in a much greater degree, by using a pair of crystals of sulphate of iodo-quinine, more commonly known as *Herapathite*, from its discoverer, the late Dr. William Bird Herapath. This salt is prepared by a tedious and com-

plicated process, and described in a communication by Dr. Herapath to the Royal Society, and quoted in many microscopical works ("Micrographic Dictionary," second edition, p. 590). The obtaining of large regular crystals fit for polariscopes is a matter of great difficulty; and, unless the student is very expert in chemical manipulation, he is recommended not to attempt it. Small specimens fit for

FIG. 36.



microscopical examination may, however, easily be made. This salt is the most powerful polarising agent known. If two crystals are superposed with their axes parallel (Fig. 36, *a*), light is readily transmitted; but, if the axes are crossed, as in *b*, the parts covering each other become perfectly opaque to transmitted light. This can easily be seen in a slide of the crystals mounted as a microscopical object, as some of the crystals are sure to be in this position.

The sky possesses the power of reflecting polarised

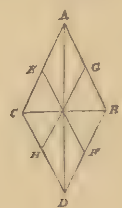
light. If the observer stands with one shoulder directed to the sun, so that he faces a point 90° from it, and looks at a white cloud through a Nicol prism, he will find that the light reflected from the cloud is polarised, and that, as the prism is rotated, the cloud will alternately appear as a white cloud on a dark ground and a dark cloud on a light ground.

The effects here described may readily be seen without the special apparatus of mirrors, &c., by any one who has a microscope fitted with the usual polarising apparatus of two Nicol prisms. If the larger one, *the polariser*, be put in its place below the stage, and the mirror so arranged that the light of a lamp or daylight be directed through it, it will be found, upon rotating the prism in its fitting, that no change is apparent, as the light, although polarised, is transmitted in every position of the prism. If the small prism, or *analyser*, be now put in its place, either over the object-glass or, better still, over the eye-piece, it will be found that the alternate transmissions and stoppages of light take place. If a film of *selenite* be now placed on the stage of the instrument, it will be found that the light will be coloured; and, when one of the prisms is rotated 90°, the colour will change to the complementary tint. For instance, a film that transmits red light in one position of the prisms will transmit a green of such quality as to produce white light, were the two mixed. Blue would produce orange every quarter revolution; and so on through the other tints of the spectrum. Similar effects are produced by using

films of mica, and all crystals possessing the property of double refraction.

To understand these changes of colour, it will be necessary to describe the direction of the axes of a crystal of selenite, which is represented in Fig. 37.

FIG. 37.



A, D and C, B being the position of the depolarising axes, and E, F and C, H that of the optic axes. To understand the powers of these regions of the crystal, it will be necessary to try another experiment, which, although more advantageously shown with a large polariscope, can be done sufficiently well under the microscope. Let the film of selenite be so mounted as to be capable of rotation. If the stage of the microscope is capable of concentric rotation, no further contrivance is necessary. If the prisms now be arranged for the production of colour, and the selenite slowly rotated, it will be observed that the colour gradually disappears. On continuing the rotation, it increases, and regains its intensity. If the amount of rotation is noticed, it will be found that the disappearances coincide with the position of the optic axes, E, F and G, H, while the greatest

intensity of colour is produced when the plane of polarisation passes through the depolarising axes, A, D and B, C. If the analyser be removed, no colours are to be seen; it is therefore evident that the analyser plays some important part in the production of these colours.

The selenite, being a doubly-refracting crystal, causes the ray of polarised light to be divided into two, which are, as usual, polarised in perpendicular planes, and, reaching the eye together, no colour is produced; but, if the analyser is added to the combination, the colourless image is broken up into two coloured ones, one only of which reaches the eye. If, instead of the Nicol prism, a contrivance known as the "double-image prism" be used, which will transmit both rays, but in a separate condition, the two images of complementary colours will be seen at once, and, if, by a suitable contrivance, they be made partially to overlap, the part where they join will be white, produced by the union of the two complementary tints.

The position of the optic axes may be easily observed in the corpuscles of starch and other polariscope objects which produce the well-known black cross, which indicates in a very marked manner the situation of these axes of no polarisation.

The apparatus employed for the examination of microscopical objects by means of polarised light consists of a *polariser*, *analyser*, and *retarding plate*.

The *polariser* is generally a Nicol prism, mounted so that it may be conveniently rotated; this is

attached, by a suitable fitting, either beneath the stage, or, in large microscopes, to the sub-stage movement.

The *analyser* varies, being, according to circumstances, a Nicol prism, tourmaline, or Herapathite. The *Nicol prism* is the form of analyser generally used, and can be placed either over the eye-piece or within the body of the microscope above the object-glass; in the first position it has the advantages of being easily rotated, and of not interfering seriously with the definition of the magnified image: but, on the other hand, when used with any eye-pieces but those of the lowest power, it cuts off the margin of the field and reduces it to an injurious extent; this is owing to the prism, by its thickness, causing the removal of the eye to some distance from the eye-glass, although the Nicol prism, when intended for use as an analyser, is generally made as short as is consistent with efficient action. When the prism is placed within the body, it does not cut off any portion of the field, but the interposition of a dense substance, like Iceland spar, impairs the corrections and consequently the definition of the object-glass, and also causes some loss of light. It is much to be regretted that in many of the smaller microscopes no other provision is made for the placing of the analysing prism. When the binocular is used with polarised light, the analyser can be placed in no other position, and it is usually mounted in a short adapter so contrived that the prism can be easily rotated. It is well to have the means of using

the analyser in both positions, that choice can be made of that best adapted to the kind of observation in progress; if very perfect definition is of less consequence than a field of full dimensions, as in viewing such objects as crystals, in which very little detail is to be seen, then the prism in the body may be employed with advantage; but should the formation of an image very perfect in its details be required, then the prism must be placed over the eye-piece.

Tourmaline, when it can be obtained of sufficiently pale colour, makes a good analyser, from its thinness it can be used over deep eye-pieces without cutting off the field; good stones are, however, scarce, and consequently expensive, as many light coloured specimens do not polarise well. The tourmaline is mounted in a brass cap similar to the one placed on the eye-piece, which is to be removed and the analyser substituted. Crystals of *Herapathite* polarise more powerfully, and are much lighter in colour than the palest specimens of tourmaline, and when they can be procured make very perfect analysers; they are extremely thin, and do not interfere at all with definition, and are to be preferred in all delicate investigations. Where, however, total freedom from colour is a necessity, the Nicol prism, notwithstanding its other disadvantages, must be used.

The *retarding plate* or *selenite film* is commonly mounted, either on card, like an ordinary slide, or else in a brass plate, with a ledge to keep the object from

slipping off; this is a very disadvantageous form, as the selenite cannot be rotated, while in a perfect polarising arrangement, every part, object included, should be capable of rotation. The most convenient and useful arrangement of selenites is that devised by the late Mr. Darker, in which a series of three discs are by combination made to give as many as thirteen different tints. In large microscopes having a substage, these selenites can be mounted so as to be capable of rotation either together or separately, and also allowing the selenites to be used or not, without disturbing the arrangement of the object on the stage.* These advantages have hitherto been confined to large microscopes; but Mr. Baily has so mounted a set of Darker's selenites for the author that they can be placed upon the stage in the ordinary manner, and at the same time allow of discs being added or withdrawn and rotated, without interfering with the object; the thickness of this stage plate is no more than is necessary to contain the three discs and allow them space to move, and all complicated machinery is dispensed with. The arrangement of Darker's system of selenites appears. at first sight, somewhat complicated, but is not so in reality, and the power of obtaining such a variety of coloured backgrounds is a very great advantage. The series consists of three discs, marked $\frac{1}{4}$, $\frac{3}{4}$, and $\frac{5}{4}$, which figures represent a certain amount of retarding

* A very perfect polarising apparatus is described by Mr. J. J. Field, *Journal of the Quekett Microscopical Club*, vol., p. 215; also in *Monthly Microscopical Journal*, vol. ii., p. 276.

influence upon the wave of polarised light and consequent colour production. Besides the figures just mentioned, each disc has engraved upon its mounting the mark P.A., meaning positive axis; when the selenites are superposed with these marks coincident, the effect is, that the power of one selenite is added to that of the other; for example, if the $\frac{1}{4}$, and $\frac{3}{4}$ discs are so placed, the power will correspond to the sum of the numbers, viz, $\frac{4}{4}$, but if the $\frac{1}{4}$ be turned round 90° then the $\frac{3}{4}$ will have only a power of $\frac{2}{4}$, the crossed position of the $\frac{1}{4}$ subtracting instead of adding its power to the $\frac{3}{4}$. The experiments with selenite films already described will have prepared the student to understand the cause of this; it will be recollected that the colour disappeared when the selenite passed through one of the optic axes of the selenite, provided the position of the prisms remained the same. If, instead of moving the disc 90° it be only moved 45°, the effect will be to neutralise; instead of giving a negative power the result will be the same as if the selenite were withdrawn. The following table of the arrangement of Darker's selenites may be useful to those who possess the series. The colours vary somewhat in different sets, so the table must be made out by each observer for his own use.* The colours in the following table are those given by Richard Beck in his work on "The Microscope:"—

* It will be better in making out this table to imitate, as closely as possible, the tint produced by the selenites, instead of attempting to express it in writing, as the English and, indeed, all other languages are very defective in words indicating colour.

		Prisms at right angles.	Complementary tint.
1.	$\frac{1}{4}$ by itself ..	Very light lavender.	Straw colour.
2.	$\frac{3}{4} - \frac{1}{4}$	Darker do.	Light yellow.
3.	$\frac{3}{4}$ by itself ..	Deep blue.	Light maize.
4.	$\frac{3}{4} + \frac{1}{4}$	Very light blue.	Orange.
5.	$\frac{9}{4} - \frac{3}{4} - \frac{1}{4}$ ..	Lake.	Emerald green.
6.	$\frac{9}{4} - \frac{3}{4}$	Deep blue.	Bright yellow.
7.	$\frac{9}{4} - \frac{3}{4} + \frac{1}{4}$ ..	Light green.	Light purple.
8.	$\frac{9}{4} - \frac{1}{4}$	Light plum colour.	Pea green.
9.	$\frac{9}{4}$ by itself ..	Blue green.	Salmon.
10.	$\frac{9}{4} + \frac{1}{4}$	Green yellow.	Mauve.
11.	$\frac{9}{4} + \frac{3}{4} - \frac{1}{4}$ ..	Pink light.	Green.
12.	$\frac{9}{4} + \frac{3}{4}$	Light pink.	Deep green.
13.	$\frac{9}{4} + \frac{3}{4} + \frac{1}{4}$ ..	Very light red.	Stone green.

From the explanation already given of the various modes in which light may be polarised, it is evident that one-half of the illuminating power is thrown away by the use of the polarising prism; this loss becomes a very serious matter when high magnifying powers are used, and as much valuable work is to be done by employing polarised light in combination with objectives of $\frac{1}{2}$ inch and shorter focus, it becomes necessary to find some means of increasing the intensity of the illuminating pencil under such circumstances. Polarised light can be concentrated by lenses in the same manner as common light, and, after condensation, still retains its peculiar properties. In large microscopes, provision is made for fitting the Nicol prism below the achromatic condenser, and a set of Darker's selenites between them; this, with a good tourmaline or Herepathite for an analyser, will enable observations to be carried on with very high powers, and with nearly the same ease as by ordinary illumination. With small

microscopes, Collins's Webster condenser, which is constructed to carry a Nicol prism, will be found a very efficient illuminator, as its lenses are large; and as it supplies an excess of light when used without diaphragms, it will be found very suitable for polarising purposes. Its capability of being adapted to any instrument is another recommendation. The author can speak favourably of its performance with his own microscope, in which the unusually short distance between the stage and mirror prevents the use of any other condenser. The selenites can be placed between the Nicol prism and the condenser, as usual in microscopes with substage fittings, but with small instruments the stage arrangement must be used; the focus of the Webster is sufficiently long to work through the three selenites without material injury to the illumination, when Mr. Bailey's or other thin mounting is employed.

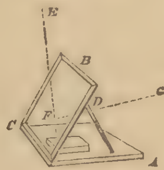
In carrying on observations by the aid of polarised light, it is necessary that the substance to be examined should be rendered as transparent as possible, by immersion in a suitable medium. Those which render objects so transparent that the details are almost invisible under ordinary illumination, are in general very suitable for polariscope purposes.

The facts which polarised light reveals are principally differences of density in tissues, the existence of which we should not be aware of without such aid. With regard to crystals, the polariscope at once distinguishes those which belong to the cubic system, such as common salt, which has no doubly

refractive power, and, in common language, does not polarise, from those of the other systems, which, owing to their double refraction, are among the most brilliant of polariscope objects. Not only differences of density are made evident by the use of polarised light, but also minute variations of thickness when the substance examined is possessed of doubly refractive properties, which are at once shown by a difference of colour, which defines the boundaries of the thickened portion, although this from the hyaline nature of the substance might be perfectly invisible when illuminated in the ordinary manner. This is very often the case with the secondary deposits in vegetable tissues, which are to be seen most clearly when viewed with polarised light and sufficiently high powers. Sections of such substances as horn, and tissues resembling it, as whalebone, &c., which exhibit little or no structure with common light, at once display differences of density indicated by colour when examined with the polarising microscope. A very interesting microscopic object is made by Mr. Bailey, consisting of a bar of glass, which is capable of being pressed by a screw. This, when examined by polarised light, exhibits no doubly refractive appearances so long as the screw does not touch it; but when pressure is applied, dark or coloured bands make their appearance around the point of the screw, extending to a greater or less distance, according to the amount of pressure employed, showing at once that some change has taken place in the molecular arrangement of the glass.

Nearly similar bands are to be seen along the sides of a recent diamond cut, and around the dot made by a slight blow of a steel centre punch, in both cases showing that the glass has been subjected to some strain. Opticians, in fitting lenses into cells, are careful to avoid pinching the glass, lest double refraction should be produced. Coloured bands are easily seen in pieces of thick plate-glass which have been rapidly cooled. These are best shown in Lecount's polariscope (Fig. 38), in which the polarised

FIG. 38.



ray, G, is made to pass twice through the piece of unannealed glass, F, which very much increases the intensity of the coloured bands. In this simple instrument the bundle of glass plates, B, acts as a polariser by reflection, and at the same time as an analyser by refraction, the light being reflected from the bundle through the object, and returned through it by the mirror, C, the bundle analysing the polarised ray, F, on its passage through it to the eye at E. The colours produced by varying thicknesses of selenite may be seen with the microscope in a small piece, roughly split, and mounted in balsam. It will be found that there will be a change of colour at every difference of thickness.

The object should be viewed, in the first instance, with the selenite plate, and the appearances noted which present themselves when both analyser and polariser are rotated. If the construction of the microscope permit, the object itself should also be rotated. Should no effect be produced by the prisms alone, a selenite may be used, commencing with one of little retarding power, as ¼ of Darker's series. This should be rotated, and also the prisms, before going through the various degrees of retardation.

Substances having a very feeble doubly refractive power are much assisted by using a selenite of suitable thickness, and details are often better seen with selenites of one colour than another. Darker's series offers great facilities for readily obtaining the most suitable tint. When a less power than that given by the ¼ is required, it can be obtained by turning the plate more or less towards one of the optic axes, which are situated at 45° from the P. A. mark, and the other depolarising axes. Also by using plates of mica, thin enough to just let a little light into the darkened field. Care should be taken to use sufficient light, and employ the condenser whenever necessary. As a general rule, with high powers, the light cannot be too strong; sometimes direct sunlight may be used with advantage. The effect of increase of illuminating power with the polariscope is not that of dilution, like excess of light pouring through a transparent coloured object, but as the coloured wave is augmented, intensity of colour and stronger definition is the result.

The polarising microscope is a great aid to the knowledge of structure, and an examination cannot in any way be considered as complete in which this most searching mode of investigation has been neglected. Hitherto, the polariscope has been considered rather in the light of a toy than as a valuable instrument of research, and it has therefore become necessary to devote so much of this elementary course of instruction to the application of polarised light to microscopical purposes.

CHAPTER VII.

THE processes of recording microscopical observations are scarcely less important than those employed in making them. The facts accumulated by the most painstaking observers are of comparatively little use unless means are found of preserving and communicating them to others. This is particularly the case with regard to microscopical studies, and, like most natural-history observations, written descriptions, however graphic, are scarcely intelligible unless accompanied by truthful drawings. The concluding portion of these papers could, therefore, hardly be considered as complete without some mention of the way of writing this language of all nations, a subject which has, with a few exceptions, met with but little attention from writers on the microscope: probably being very expert themselves, the idea prevailed that drawing was as natural an acquirement as writing, and that no special directions were needed. The lectures which supplied the matter for these pages being intended for persons

wholly unacquainted with the use of the microscope, it was then deemed advisable to treat upon the subject of microscopical drawing and micrometry at greater length than usual, dwelling especially on those points upon which little information is to be found in books; and the author has seen no reason to alter his opinion since the delivery of the lectures, but has rather added than withdrawn matter.

Photography, from its extreme accuracy and delicate rendering of details, claims a very high place among the resources of microscopical art. When the object is suitable for its employment, the result is not to be equalled by any other means of delineation. The conditions, however, which it is requisite to comply with in order to obtain a successful micro-photograph somewhat limit the cases in which it is available. The object to be photographed should be very thin and flat, so that the whole, or the greater part of it, lies in the same plane, that it may all be in focus at once; the reduction of aperture commonly used by landscape photographers to secure focal depth not being practicable, on account of the great loss of light occasioned by the use of small diaphragms, which is so great when the object is much magnified as to render the production of an impression on the prepared plate impossible with any reasonable amount of exposure. This is a very great drawback, as many of the most interesting microscopical objects can scarcely be seen without continual alteration of the focal adjustments. The colour of the object should also be such as is favour-

able for photographic purposes; the yellow, brown, and red tints of many tissues render it impossible to obtain any satisfactory result. The best photographs are always those obtained from colourless objects, such as the *Diatomaceæ*, the delicate sculpture on the frustules of which are marvellously rendered; as may be seen by examining the photographs by Dr. Maddox, to be procured of Mr. How, of Foster Lane, at a merely nominal price.* So minutely are the details produced that they will, when photographed upon glass, bear a considerable amount of enlargement by means of the magic-lantern.

At present only objects illuminated by transmitted light have yielded impressions on the prepared plate, the more feeble images obtained from reflected light and dark field illumination have failed in producing photographs, and so a large and interesting class of objects is excluded. Possibly future improvements may remove this, and some other difficulties which at present limit the use of this valuable art. The necessity of employing special apparatus and of mastering a delicate set of chemical processes will, it is to be feared, prevent many microscopists from availing themselves of photography as a means of delineating the objects presented to them in the course of their studies.

The practical details of manipulation and the bibliography of the subject are treated at considerable

* A fine series of microphotographs by Colonel Woodward, of the United States Army Medical Department, is in the possession of the Royal Microscopical Society. Also several by Dr. Maddox and others.

length in Dr. Beale's "How to Work with the Microscope," 4th edition, pp. 229 to 279.

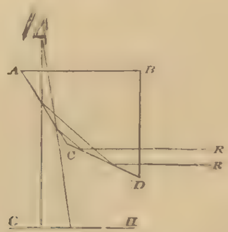
Fortunately, the other processes used in making representations of objects are within reach of the majority of microscopists. The apparatus being simple and inexpensive, compared with that needed for obtaining photographs, and the use of it so easily mastered, that, with a little perseverance, most persons will be found able to obtain drawings really useful, although, perhaps, somewhat wanting in finish and delicacy. Even these may be attained in some degree by painstaking application; and, although the student's productions may not equal the work of professional artists, they will be found to possess an amount of truth which would most likely be wanting in the work of a more accomplished but less scientific draughtsman.

The simplest, but not the easiest, method is to make the drawing without instrumental aid. Few but those who are expert draughtsmen can accomplish this. The difficulty of obtaining anything approaching an accurate representation can only be understood by those who are familiar with the process. The chief obstacle is the impossibility of seeing object and drawing nearly together, as in landscape or other sketching, and the consequent trouble occasioned by frequently losing the place, especially during the earlier stages of the outline; the peculiar view afforded of the object depriving the observer of those guides used in ordinary drawing from nature. The impossibility of making

the drawing to scale is another disadvantage, and renders it of but little value as a microscopical record. For objects in active motion no other mode is available, and in such cases it is of value, also, for making slight sketches and memoranda during observations, and preserving facts which would otherwise be lost; but where considerable accuracy is needed some one or other of the instrumental appliances now to be described must be employed. Nearly all the instruments attached to the microscope with a view to aid delineation act upon the principle of rendering the image of the object and the paper and pencil-point visible together and apparently blended. This may be accomplished in several ways, although the principle of reflection is used in all cases.

The oldest of these instruments is the *camera lucida* of Dr. Wollaston; it consists of a four-sided glass prism (Fig. 39), of which the angle A, B, D

FIG. 39.



equals 90°, the angles B, A, C, and B, D, C, 67° 30′, and the angle A, C, D, 135°; it acts by twice

reflecting the rays R and R′, proceeding from the eye-glass of the microscope, which enter through the side B, D, first at C, D, and afterwards at A, C, to the eye, so placed at A that one-half of the pupil is over the edge of the prism, and views the image of the object in the microscope, the pencil and paper being seen by the other half, which is placed beyond the edge A. As the reflections are internal,* there is scarcely any loss of light; the image is consequently very bright, and owing to its being twice reflected, it is not inverted when it reaches the eye. The prism is mounted in a convenient setting, so that it may be fitted over the eye-piece in the place of the cap, which is of course removed. A lens is sometimes attached to the lower part of the camera lucida, between the eye and the paper; this is of use to persons who cannot see the drawing distinctly at the usual distance, about ten inches, and may be either convex or concave, according to the special requirement of those using it.

A small steel disc, known as *Soemmering's mirror*, placed at an angle of 45°, is used by some microscopists. The polished disc is smaller than the pupil of the eye; so that, while the image from the microscope is viewed by the centre of the pupil, its circumference is employed in viewing the pencil-point and paper, upon which the image appears to be projected, as in the camera lucida.

Another contrivance, and one which has the

* *Ante*, p. 110.

recommendation of being procured at a very small cost, is the *neutral tint reflector* (Fig. 40). It con-

FIG. 40.

sists of a small plate of glass, with surfaces accurately parallel, and slightly coloured, so as to improve its reflecting qualities, but not sufficiently dark to prevent the paper from being easily seen through it. This is placed, as before, at an angle of 45°. As the instrument is commonly constructed, the tinted glass is a fixture, and the setting too long; so that the mirror is removed to a greater distance than is advantageous from the front glass of the eye-piece; this contracts the field so much, when any but an eye-piece of low power is employed, that it is almost useless. This defect is remedied in the form here represented, in which the mirror is brought as close as possible to the eye-glass. The tinted glasses are also removable, so that a change of tint may be made, as it will be found sometimes that one tint suits the eye better than another. Some microscopists, instead of tinted glass, use a piece of thin cover-glass,

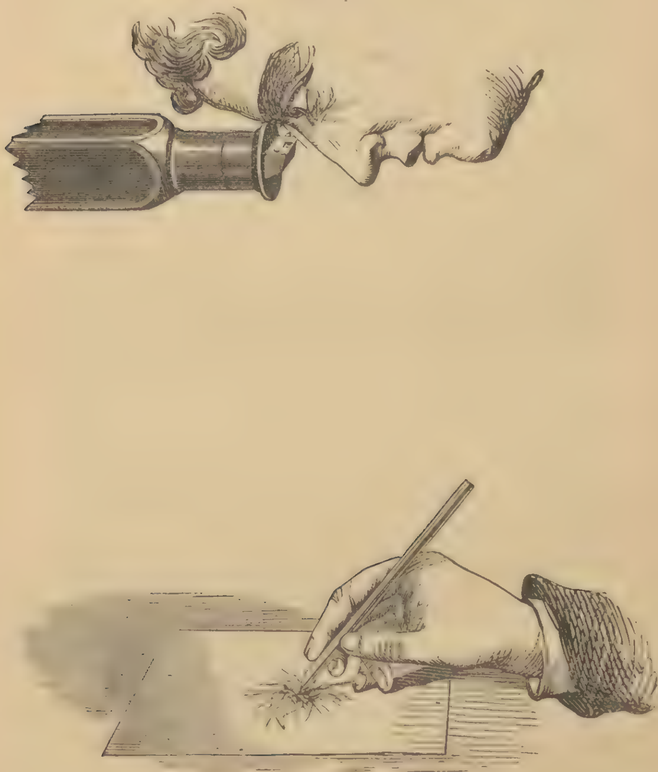
which gives a very good reflection, and can easily be used with this form of setting, which also allows a small right-angled prism to be placed in it, and which, although not usually supplied with the instrument, will be found a serviceable addition. Its use will be described with that of the preceding instruments. This reflector gives a reversed view of the object by a single reflection, as in the steel mirror of Soemmering, but, unlike it, the paper, instead of being viewed round its edge, is seen through the glass.

As these instruments have much in common, the use of them may very conveniently be described together, noticing, in passing, such peculiarities as render them more or less serviceable, each having its own special advantages and defects.

The microscope should be placed with the body in a horizontal position (Fig. 41), and, if the stand is not of suitable height, it should be placed on a box or other convenient support. The best distance between the eye and the paper, for general purposes, is 10 inches, this being the standard distance employed in estimating magnifying power; but any other that is convenient may be made use of, bearing in mind that the greater the distance from the eyepiece the larger will be the image; so that the size of the picture is capable of being regulated at will, the only limit being the difficulty of seeing the pencil when too near, and the trouble of drawing with a pencil attached to a long stick if the paper is greatly removed from the usual position.

With respect to the images formed by the several instruments, the camera lucida, as it reflects doubly, has the advantage of giving the image in the same position as when viewed through the micro-

Fig. 41.



scope directly, which, owing to its perfect internal reflection, is brilliant and well defined. Soemmering's mirror and the tinted-glass reflector reverse the image, just as an ordinary looking-glass. This is of little consequence if only slight outline sketches are required; but, when the drawing is to be highly finished, which is always done by viewing the object directly through the microscope, this reversal becomes excessively troublesome to those who are not, like engravers and lithographers, accustomed to reverse their drawings.

With a view to obviating this inconvenience, the author uses the small right-angled prism before mentioned, when drawing with the neutral tint reflector, which enables the drawing to be completed, as it reverses the image just as the tinted glass; and, as the reflection from the internal surface of the prism is total, the view is nearly as brilliant as that received directly from the microscope.

Only one eye is to be used while drawing, and great care should be taken to maintain its position steadily until the sketch is finished (Fig. 41). With the camera lucida and Soemmering's mirror, the maintenance of this position is somewhat painful, when much prolonged, owing to the divided manner in which the eye receives the light from the object and the paper; and frequently the power of seeing the pencil and drawing is lost after a few minutes' use. With the neutral tint reflector, the view of both object and paper is much easier; and, when

the reversal of the picture is immaterial, it is, as far as comfort is concerned, much to be preferred.

The illumination is a matter of great importance in making use of drawing instruments. Care should be taken not to light the object more than is necessary, while it will generally be found advisable to illuminate the paper rather strongly. If the image of the object is too bright, it will be found impossible to see either the pencil-point or the line it is tracing. The camera lucida requires far more care, in this respect, than the tinted mirror.

The author's practice is always, when drawing, to use two lamps; one the little camphine lamp before mentioned,* which is used exclusively for the microscope; the other a large paraffin lamp, with shade, which lights the paper. By this means, the relative illumination of the object and paper can be very nicely adjusted—a matter of some difficulty when only one lamp is employed.

These instruments are only used to secure an outline, and mark out other main points, the details being filled in by free-hand drawing, which will be found comparatively easy when an accurate outline is obtained to work upon.

If, when the sketch is finished, before removing the reflector, a ruled micrometer-scale is placed upon the stage of the microscope, the lines can be seen projected upon the paper, just as any other object, and, by tracing some of them, a

* *Ante*, p. 26.

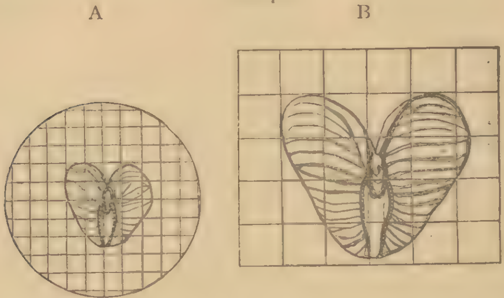
scale can be formed by which the drawing can readily be measured with a pair of compasses, like a map. This is one of the simplest methods of micrometry.

The magnifying power of the microscope can also easily be ascertained by means of the camera lucida or neutral tint reflector and the stage micrometer. By placing the microscope in the position for drawing, taking care that the eye-piece is 10 inches from the paper, the image of the micrometer-lines, instead of being projected on a sheet of paper, is caused to fall upon a divided scale; and, from the amount covered by it, the magnifying power can be estimated; for instance, the 1-inch objective, with No. 1 eye-piece, causes 0·01 of the micrometer to cover 0·5 inch of the measure on the table; the magnifying power will be 50 diameters. The ¼-inch makes 0·01 cover 2·5 inches; the power will be 250 diameters. And so on, for other objectives and eye-pieces.

Finding the placing of the microscope in a horizontal position troublesome, and not liking the constraint of the camera lucida, the author thought that the method of enlarging and reducing drawings commonly employed by artists might be adapted to the microscope. This process consists of ruling a series of squares of convenient size on the drawing to be copied, or placing over it a lattice of threads crossed in squares. The copy is then made upon a sheet of paper or other material, ruled, either in augmented or diminished proportion, as may be required. Messrs. R. and J. Beck ruled a disc of

glass in squares (Fig. 42), the side of each of which,

FIG. 42.



for convenience sake, was made to correspond with 10° of Jackson's eye-piece micrometer. This disc was dropped into the eye-piece, and rested on the stop, so that, when in use, the field appeared similarly divided (Fig. 42, A). A sheet of paper (Fig. 42, B), ruled in squares of convenient size was employed to make the drawing upon; and, by noticing how many squares the object covered, the direction of the various lines—whether, for instance, they ran through the sides or the corners of the squares—and setting them down in similar positions on the ruled sheet, the author found that an accurate drawing might be made with great ease and expedition, and without the trouble of moving the microscope out of the usual inclined position, which is generally the most comfortable for observation. The use of the binocular did not cause any impediment, and the ruled disc only slightly interfered with the definition of the object, and could easily be removed, when its services

were no longer required, without disturbing the arrangement of illumination, object, or instrument. When large diagrams are wanted, nothing more is necessary than to use a large sheet of paper, ruled in squares of suitable dimensions, and the object can be rapidly delineated in this augmented proportion.

The measurements can be made either by obtaining the value of the side of a square of the disc with each objective and eye-piece, by means of the stage-micrometer, or by selecting two well-marked dots or lines in the object, and measuring their distance with the eye-piece micrometer, and using the distance obtained from the corresponding part of the drawing as a standard for the formation of a scale. These processes will be explained in the account shortly to be given of micrometers.

When many sheets of paper are required to be ruled in squares (and it will be found in practice that two or three sizes will be in general request), they can easily be made by placing a perforated sheet over the sheet to be ruled, and rubbing over it a piece of wash-leather dipped in black-lead powder, which will pass through the holes and leave a series of dotted lines on the sheet below, which will be sufficiently distinct, and have the advantage of being rubbed out with a very light touch of the india-rubber, without affecting the pencil-lines of the drawing. The perforated sheets are easily made by means of a comb-like steel punch used by harness-makers, which cuts a row of small pin-holes, equal in length to its own

width, which may be an inch or more. This instrument can be obtained at the better class of tool-shops.

Some microscopists have endeavoured, with more or less success, to make drawings from the image of the object projected upon a sheet of paper or ground glass, after the manner of the solar microscope or camera obscura. All the contrivances for this purpose seem to have the defect of giving a very faint image, unless a light of greater intensity than that of ordinary lamps is employed. The image must be received in the dark, which is troublesome, as the outline cannot easily be seen. The process is only applicable to those objects which can be viewed by transmitted light, besides putting the microscope more out of its usual position than the camera lucida and other reflecting instruments.

Intimately connected with microscopical drawing is the subject of *micrometry*, the practice of the two together forming the records and statistics of histological science. The contrivances used by the earlier observers were rude in the extreme. Leeuwenhoek compares the dimensions of magnified objects with grains of sand. Dr. Hooke, with a little more approach to exactness, used fine silver-wire. By winding a quantity of this closely round a thicker wire, he noticed how many coils there were in an inch, and used the unit so obtained as a means of measurement. The most perfect of the old micrometers is a somewhat complicated contrivance attached to a microscope by the famous Benjamin

Martin, now in the possession of the Royal Microscopical Society. It consists of a separate stage, which is placed on the instrument when measurements are required to be taken. The object is capable of being moved through a definite space, by means of delicate screws, having large graduated heads, upon which the distance traversed by the object can be read off. This micrometer has, in common with all measuring instruments applied to the stage, the defect that any error in the graduation is multiplied by the whole magnifying power of the instrument.

The standards employed in microscopic measurements are the ruled slips of glass before mentioned. They are graduated by a machine invented by the late George Jackson, and are now to be obtained of most opticians. They are ruled in hundredths and thousandths of an inch, and are marvellously accurate in their divisions, and extremely fine in the engraving of the lines, bearing a very high magnifying power without appearing coarse. Scales are also ruled in millimetres. The millimetre equals 0·03937 English inch, or about 1-25th of an inch. As the metric system will probably in a few years be universally adopted, it is well to place both scales on microscopical drawings, especially as this system of measurement is common on the Continent.

One method of measurement has already been mentioned in describing the use of the camera lucida.

To obtain the greatest degree of accuracy in microscopical measurements, it is desirable that, while

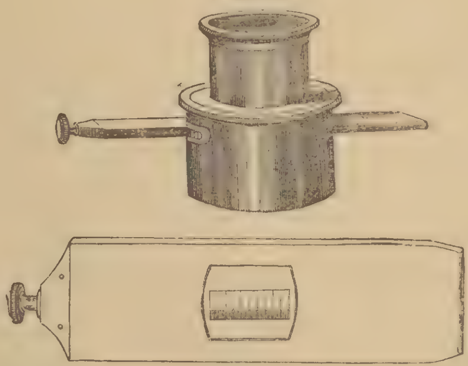
the object to be measured is magnified as much as possible, the measuring scale should be but slightly enlarged. This is effected by the use of eye-piece micrometers. The most delicate of these is the well-known *cobweb micrometer* of Ramsden. It is nearly similar to that employed in astronomical instruments, and consists of a positive or Ramsden's eye-piece, in the focus of which is placed a pair of stretched cobweb-lines, one of which is fixed, and the other movable by means of a fine screw which has a large graduated head. The value of the graduations has to be determined for each object-glass, as is the case with all similar contrivances. The cobweb micrometer, when used with a sufficiently high power, is capable of measuring extremely small portions of space with great exactness; the instrument, however, is rather expensive.

With a view to avoid the multiplication of apparatus, the late George Jackson, by a simple contrivance, rendered the ordinary Huyghenian eye-piece available for micrometric purposes. A slit was cut on each side just above the diaphragm (Fig. 43, A), which served to admit a brass slide, B, containing a scale ruled on glass, which, when in position, was in the focus of the eye-glass, and could be seen in the field at the same time with the object in the microscope. The scale is ruled with a long line at every fifth division, and a still longer one at every tenth, for facility of reading. The scale is allowed a small amount of lateral motion, which is controlled by a fine screw acting against a spring on the opposite

side. This movement enables the line from which the measurement commences to be brought to the edge of the object more accurately than it could be

FIG. 43.

A



B

by means of the stage movements, as the scale of the eye-piece micrometer is only magnified by the trifling power of the eye-glass, while the motion of the stage-racks is enlarged by the whole power of the instrument. The operation of measuring is nearly as easy as applying an ordinary rule: the scale is brought over the object, adjusted by the screw, and the number of degrees read off in the direction required.

To determine the value of the degrees, which differs with each objective, the following process must be adopted:—

Place the micrometer in its eye-piece, and focus,

if necessary, for distinct vision of the scale by unscrewing the eye-glass, which is usually provided with a rather long screw for this purpose. Screw on the objective, and place the ruled scale on the stage; and, looking through the microscope, focus until the lines are sharp and distinct. Suppose the value of the micrometer is to be ascertained for the $\frac{2}{3}$ object-glass, and it is found that 1-1000th of an inch of the ruled scale on the stage occupies a little less than two divisions of the micrometer, this will give an awkward number for calculation; so it will be necessary to increase the power of the microscope to such an extent that the 1-1000th should occupy 2° exactly. This can be done by lengthening the body by means of the draw-tube, which, for this purpose, should be divided into inches and tenths, that the amount of extension may be noted. The tube is to be drawn out until the divisions of the stage micrometer coincide with those of the eye-piece micrometer. Say, for example, it is found that, to effect this, the tube has to be lengthened 3-10ths of an inch; then, as 1-1000th of an inch equals 2° of the eye-piece micrometer, 1° is equal to 1-2000th of an inch. This process should be repeated with each object-glass, and tried several times, to ensure accuracy. The result should be preserved in the following tabular form:—

VALUE OF DIVISIONS OF EYE-PIECE MICROMETER.

Objective.	Draw-tube.	Vulgar Fraction.	Decimal.
$1\frac{1}{2}$	13	1/[illegible]	·001
$\frac{2}{3}$	3	$\frac{1}{2000}$	·0005
$\frac{4}{10}$	22	$\frac{1}{4000}$	·00025

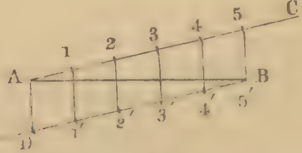
And so on through the whole series of objectives. The slight alteration of distance between the anterior combination and the back lenses caused by turning the graduated collar which regulates the adjustment for covering glass with the higher powers, slightly alters the magnifying power; and, when very accurate measurements are required, the draw-tube correction must be ascertained for each degree of the adjustment-collar. The value of the divisions of Ramsden's or the cobweb micrometer is calculated in the same manner. When this table is once made, measurement with the eye-piece micrometer becomes very easy indeed. After selecting the object-glass and placing the micrometer in the eye-piece, draw out the tube to the number of tenths indicated in the table, and then the degrees can be read off just like an ordinary measure. To secure accuracy in measuring, always use the highest convenient magnifying power, as the readings can be made with greater minuteness; for instance, a degree with the 4-10th or ½ equals 1-4000th of an inch; while, with the ⅛, it would be 1-16000th, and half a degree can easily be estimated by the eye; so, by using the higher power, the 1-32000th of an inch can easily be measured, and greater minuteness still can be obtained by using higher powers, where practicable.

A convenient mode of measurement has been devised by Dr. J. Matthews. It is an adaptation of the indicator, sometimes placed in the eye-piece to mark a spot in the field. Two of these pointing needles, suitably curved so that they act, by means

of milled-heads, like a small pair of callipers, are placed as just mentioned. The distance on the object is measured between these points, and, upon the removal of the slide, the value of the space can be estimated by putting the stage micrometer in its place. For counting striæ and other marks in a given space, and for many purposes, this simple contrivance is very effective, as, also, where the glass of the stage micrometer might interfere with the definition of a very delicate object.

In making the scales on microscopical drawings, it is often necessary to divide a given space into a certain number of equal parts. When the number is a multiple of two, it is readily performed by a continued process of bisection; but, as ten is a number frequently required, this process will not serve beyond the first bisection, which leaves five—a rather troublesome number to guess at with the compasses. Suppose the line A, B (Fig. 44) is to be

FIG. 44.



divided into five parts. From A, rule the line A C at any convenient angle, of any suitable length; from B, rule B D, parallel to A C; from A, set off, with the compasses, five equal spaces (1, 2, &c.) towards C; and, from B, set off the same towards D; join

1, 1′; 2, 2′; 3, 3′; &c.; and the lines 1, 1′, &c., will divide A B into five equal parts. Any number of divisions may be made by setting off the number required on A C and B D.

If scales are employed for setting off distances, those known as "feather-edged scales" are to be preferred, as they do not require the use of compasses, the divisions being marked directly on the paper from the thin edges. For general purposes, that known as a builder's scale is convenient, as it contains a large number of different scales, all of which are ingeniously contrived to read at the edges. It should, however, have the sub-divisions in tenths, and not, as usually made, in twelfths. A millimetre scale will also be found useful.

The subject of drawing materials is of some little importance, and, as it is not treated upon in any microscopical work, a few remarks may not be out of place.

Probably no material is capable of representing elaborate microscopical subjects with so much truth as *water-colour*. When used with all the appliances of the modern school of painting, both colour and texture can be very closely imitated by skilful artists; but few have turned their attention to this subject; and, as the process is costly and not easy to acquire without a considerable amount of study, the use of this mode of representation will, in all probability, be very limited. Those who possess the requisite skill are strongly recommended to make use of it. Even as pictures, groups of aquatic animals and

plants are quite as beautiful, both in form and colour, as flower compositions; and no other means of delineation, excepting the still more difficult art of oil-painting, can approach the truth of a highly-finished water-colour drawing. Unfortunately, at present, no means exist of re-producing these beautiful pictures, as their extreme delicacy places them beyond the powers of chromo-lithography.

The effect of outline sketches is much improved by the judicious employment of tints of water-colour; and this is by no means a difficult process, as it is a mere matter of laying on colour; while, in painting proper, quite as much is done by taking off paint as by putting it on, and also every advantage is taken of the texture of both paper and pigment.

Pencil drawing is particularly useful for microscopical purposes. Fine lines can readily be made, and the shading is capable of much refinement, so that very delicate tissues can be faithfully delineated. Unless the drawing consists entirely of fine lines without shaded tints, the use of hot-pressed or perfectly smooth paper is not to be recommended, but one having a small, fine grain is to be preferred. The paper should always be supported behind on some hard substance, otherwise the pencil-point will cut in, the line be difficult to rub out, and also much of the power of guiding the pencil lost. For delicate drawings, a piece of thick plate-glass makes an admirable drawing-board. The blocks or solid sketch-books so much used in out-door sketching, when made of a suitable paper, are particularly pleasant and con-

venient to draw upon. For shading, the pencil should not be cut to a sharp point, but rather kept square. Those with extra thick leads (such as BBBB and EHB) may sometimes be used to advantage, and even the broad, flat crayons known as Harding's tablets. For general outlining with camera or ruled disc, HB, from its freedom, will be found useful. For a fine outline, H should be used. Delicate tints may be obtained by rubbing on black-lead powder with a leather stump; the most convenient is that known as "Harding's." The author has found no black-lead pencils equal to those made by Mr. B. S. Cohen; they are very even in texture, rub out easily, do not readily break, and correspond exactly with their respective marks. The 6 H, made for drawing on wood for engraving, is well adapted for the purpose for which it is intended.

Pencil drawings, and also those in chalk and charcoal, may be permanently fixed by applying freely at the back, until the paper is saturated, a varnish composed of white (bleached) shellac, made by mixing equal parts of white lac-varnish and methylated spirit. The white lac-varnish is always supplied by Messrs. Winsor and Newton of uniform strength, and will save the trouble and difficulty of dissolving bleached lac. The drawing is to be carefully dried before a fire, and, when completed, may be rubbed with india-rubber with perfect impunity. Water-colour may be freely used in combination with pencil, as it is not affected by this varnish, which does not stain the paper when dry, although it soaks in

when first applied, and renders it transparent like oil.

The multiplication of microscopical drawings is a subject worthy of the attention of every observer. With the exception of Dr. Beale,* no writer on the microscope has given any account of the various processes of engraving; and yet, unless the microscopist can command the services of the very few engravers and lithographic artists who have devoted themselves to the re-production of microscopical subjects, there is, as the author has found by experience, great risk of misinterpretation.

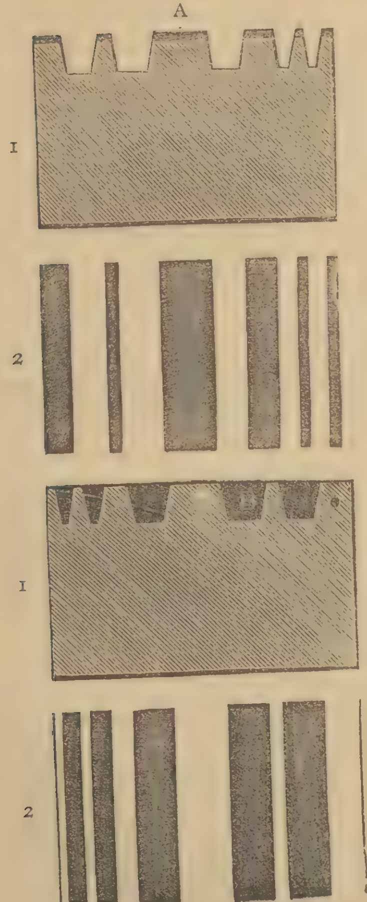
Photography is capable of copying drawings with great exactness, and has no fault saving its cost. When only a small number are required, it would probably, however, be cheaper than any of the printing processes.

The printing processes proper consist of plate and surface printing and lithography.

Copper and steel plate engraving consist of cutting lines in a metal plate with a pointed steel tool of square or rhomboidal section, known as a graver. The plate, when finished, is rubbed over with a thick printing-ink, which is afterwards cleaned off, leaving the lines full (Fig. 45, B, 1). The plate is then passed through a powerful rolling-press with a sheet of thick, porous paper over it, which is forced into the lines, and takes the ink out of them, forming the impression (Fig. 45, B, 2). Instead of excavating the lines with a cutting tool, the plate may be covered with a pre-

* "How to Work with the Microscope," pp. 28—35.

Fig. 45.



paration capable of resisting acids, known as etching-ground. The copper is then laid bare by scratching through the ground with a suitably-mounted needle. Diluted nitric acid is poured on the plate, and allowed to corrode the metal. When sufficient depth is obtained, the acid is poured off. Those lines which are "bitten" sufficiently are filled up with varnish. The process of biting is then repeated until the deepest lines are sufficiently corroded. This process of *etching* is a great favourite with artists, and might, no doubt, be turned to account for microscopical purposes, as it is much easier than using the graver, which is a very troublesome tool. The disadvantage of plate printing is that the obtaining of impressions is expensive, and the number limited, owing to the rapid wear of the plate; this latter objection, however, may be overcome by copying the plate by electrotype. The variety of engraving known as mezzo-tint is well adapted for the representation of tissues; but it requires a skilled engraver, and the learning of it would take up too much of the observer's time.

Surface printing is the reverse of plate printing. In this, as will be seen (Fig. 45, A, 1), the light parts are excavated and the dark parts left standing; these receive the ink from the roller, and yield a copy to a sheet of paper upon pressure being applied (Fig. 45, A, 2). Common type is an example of this kind of printing. For art purposes, wood engraving is employed. The drawing is made on a block of box-wood, which is then placed in the hands of the engraver, who

cuts away the light portions, leaving the solid black (if any) standing, and variously modifying, by lines and dots, the portions which have a tone between black and white,—"half-tints." The process is a difficult one, requiring great skill, which is only to be acquired by very long practice. It is capable of rendering microscopical subjects with great perfection: the re-productions of Dr. Beale's drawings in his various works, by Miss Powell, are marvels of delicacy. Some beautiful specimens of wood-engraving will also be found in the work on the microscope by the late Richard Beck.* Wood-engraving has the advantage of being cheaply printed, and also of being set up along with type, although, in the latter case, its beauty is somewhat sacrificed: it never has justice done to it unless it is printed by itself, and with very great care. A valuable little book on the "Art of Wood-Engraving," by T. Gilks, is published by Messrs. Winsor and Newton.

A very ingenious printing process, known as *graphotype*, has been lately brought forward. In this, a quantity of finely-powdered chalk is compressed into a solid tablet; this is drawn upon with a fine brush charged with an ink which hardens the chalk where-ever it touches. The drawing is then sent to the patentees, who brush away the chalk, leaving the lines standing. A mould is made in plaster of Paris, from which a cast in type-metal, capable of yielding impressions in the common printing-press, is taken.

* One of these, through the kindness of Messrs. R. and J. Beck forms the frontispiece of this work.

Every facility is afforded by the Graphotyping Company, No. 7, Garrick Street, W.C., to persons wishing to test the merits of the process.

Lithographic printing differs remarkably from all the processes of multiplying impressions just described. While, in plate and surface printing, it was essential that there should be a difference of level between the parts intended to print lights and shadows, in the various lithographic processes, light and dark are all printed from the same surface. The operation is purely a chemical one, and depends upon the mutual repulsion of oil and water. The stone used is a fine-grained and very compact limestone, capable of bearing a high polish, principally supplied from quarries at Solenhofen; and it would seem that it was destined to transmit natural history information to posterity, as many of the slabs enclose fossil-insects, as perfectly preserved as if they had been shut up between the leaves of a book for a few weeks, instead of ages. The British Museum has a very large collection of these specimens of Nature's lithographs. If a grease-mark be made upon the smooth surface of this or similar stone, and it then be wetted, it will be found, upon passing a roller charged with printing-ink over the stone, that the ink will adhere to the greasy portions, while it will be repelled by the parts that are wet. If the stone, with a sheet of paper on it, be passed under the press, an impression will be obtained; and, by a series of wettings and inkings, the operation may be repeated any number of times. This is the foundation of all the lithographic pro-

cesses, which are numerous, and suited to the production of a great variety of effects, mostly by the use of means differing less from the ordinary manipulations of the artist than any of the other means of multiplying drawings. The use of grease or oil as a material for drawing upon stone is open to many practical objections; therefore, a greasy material is manufactured, more closely resembling, in form, that used in the ordinary process of drawing. It is composed of a mixture of tallow, soap, wax, and shellac, with a portion of lamp-black, to give it sufficient colour to guide the artist in making his drawing. The proportions vary according to the purpose for which it is required, and the combination of the materials is a matter of very nice manipulation. It can be procured, properly prepared, of the dealers in lithographic materials, and will be found in the form of crayons of three degrees of hardness, which are used like ordinary artists' chalks, and cakes, which are soluble in water, and can be rubbed down like Indian-ink, care being taken to use distilled or very pure water, otherwise, from the soapy nature of the ink, it will not mix freely.

In making drawings with the ink, a fine brush or suitable steel pen may be used; and, if the drawing is to consist entirely of ink-work, a polished stone should be employed. Care should be taken not to touch the stone with the fingers, as every greasy mark, although invisible when made, will print when the stone is rolled in. If the crayons, or chalk, are used, the stone should be what is called "grained,"

that is, its surface should be prepared with a texture somewhat like that of drawing-paper, to enable the chalk to be rubbed off the crayon and held by the stone. The fineness or coarseness of the grain must be suited to the nature of the drawing: microscopical drawings usually require a very fine grain. The manipulation is somewhat like that of pencil and chalk drawing on paper, only taking certain precautions rendered necessary by the nature of the material. All light tints should appear darker on the stone than they are intended to print, as they lose some of their strength in the preparation which the stone undergoes before it is printed from. Dark tints should be worked up gradually, by repeating the touch of the chalk in as many directions as possible, so that the minute papillæ, or roughnesses, which form the grain of the stone may be loaded with the chalk on all sides, and consequently suffer less in the etching process. Any attempt to produce a dark tint or spot by a vigorous and sudden touch, as in pencil drawing, will generally fail when the stone is printed. Ink outline may often be used with great advantage in combination with chalk shading. In this case, the outline should be put on the stone with the ink first, and the shading done afterwards, as it is difficult to see the ink outline when the stone is covered with shading, and the chalk is also likely to hinder the adhesion of the ink to the stone. Care should be taken that the work is perfect before it is sent to the printer, as but little or no alteration can be made after the proof is taken.

This is one of the greatest defects of lithography, and is unlike copper-plate, where the artist goes on improving and re-touching, after a series of proofs, until perfection is attained. When the printer receives the stone, he washes it with very dilute nitric acid, which converts the soapy ink into grease, and prevents its being washed off in subsequent processes. The stone is then covered with gum-water, which adheres to the parts not touched with ink, and prepares the stone to receive the wet. Then, by a series of spongings with water and rollings with printing-ink, the stone is made ready to yield a very large number of impressions. With a little perseverance and the assistance so kindly afforded by most lithographic printers,* any person who can draw may hope, after a time, to re-produce his works upon stone with tolerable success.

Another process, capable of producing very delicate results, and well suited for microscopical purposes, is that known as engraving on stone (Plate 3). It is by this mode that most of the beautiful works of Mr. Tuffen West are executed. It consists in scratching the lines and dots forming the picture with a diamond-point on a highly polished stone, of which the surface has been slightly coloured, to render the marks visible. Care should be taken not to cut deeply, but only slightly to scratch the stone. The printer rubs the engraved stone with grease, which adheres to the scratches, which, when the stone is rolled in,

* The author has been indebted to the artists in the office of Mr. West, Hatton Garden, for much valuable information.

print as black lines. This process requires much more practice than either chalk or ink drawing; but its results, when well executed, almost rival fine steel-engraving.

White-line lithography, (Plates 4, 5, and 6) on a black ground, is useful for representing many tissues. It is executed on a polished stone, which is prepared by the surface being covered either with a coat of lithographic ink or grease and lamp-black. The artist, with a diamond-point, cuts through the black ground, taking care to lay bare and slightly incise the stone. The diamond is a very free-working tool, and obeys the hand beautifully after a little practice. This process is remarkably easy and expeditious, and is worthy of having its powers developed. Very little use has been made of it at present. It seems capable of great delicacy; and, as so many microscopical observations are made on a black ground, either with the parabola or by reflected light, this process seems to be one very well suited to the wants of the microscopist. As a compensation for the ease of execution, it would seem that black-ground lithographs entail some trouble on the printer, as the fine lines are apt to fill up; but as this kind of printing becomes more frequent in use, doubtless the difficulty will be thought much less of. The author strongly recommends microscopists who have drawings to publish, and who cannot afford the cost of professional assistance, to master some one or other of the lithographic processes. Their work will doubtless, even after some practice, be rough, and

not equal to the productions of experienced lithographic artists; but it will have an advantage which is possessed by no copy of a drawing, however good: it will be an autograph, re-producing all the author's peculiarities of style, and preserving those points which are very often lost in the copying of drawings by those who are not familiar with the subjects represented.

The student who wishes to render the microscope really valuable to him must determine, after mastering the technical difficulties of his instrument, to apply himself diligently to the study of some particular subject. One of our greatest authorities (Dr. Carpenter) speaks of "microscope power running to waste" in this country. Another author says:—"We have the best microscopes in the world, and the fewest observations." And it is to be feared that there is much truth in these statements. The microscope is, in the hands of many persons, only a costly toy. It should be regarded rather as a tool, and the naturalist's most efficient one. The work of the microscope does not consist in resolving the striæ of difficult diatoms; this has been done over and over again, and yet we seem to be not much nearer the truth than before. However, if we cannot understand the markings of the diatoms, they have done us service: they have caused our instruments to be continually improved, till now it is doubtful whether much more advance can be made.

The beginner is strongly recommended to go carefully through the tables at the end of Dr. Beale's

"How to Work with the Microscope," carrying out the principles there laid down; for, though the work is principally written for students of anatomy and physiology, it may be consulted by all enquirers with great benefit. Great progress may always be made if the student has the good fortune to be acquainted with some working microscopist. Many such are glad of the assistance of others; and, although the beginner may not be able to originate an enquiry, he may confirm and verify the observations of others, and, in so doing, add largely to his own stock of knowledge.

The numerous microscopical societies in London and elsewhere offer great facilities to the young student, by giving him opportunities of becoming acquainted with the best practical microscopists.

The recent application of the spectroscope to microscopical research will no doubt be a very promising field of enquiry. Already, besides other discoveries, the distinction between two vegetable reds (those of the grape and elder-berry) has been pointed out by its means, and will probably lead to the detection of methods of adulteration which have hitherto baffled both chemists and microscopists; and many more very important results may be expected to be elicited by steady application and careful use of this most delicate means of distinguishing colour. The use of the microscope is far from being confined to those sciences which are connected with natural history. The instrument has been applied, with the greatest advantage, to researches on in-

organic matter; and much valuable information has been obtained by the observations of Mr. Sorby and others who have devoted themselves to such enquiries.

APPENDIX.

IN the following lessons, the possession of an instrument fitted with Mr. Wenham's stereoscopic binocular arrangement has been supposed. As microscopes of moderate price are now so constructed, the author has no hesitation in arranging the following simple course of exercises more especially for its use; nearly all the observations can, however, be made with the monocular instrument.

The following tables, containing lists of the objectives made by the three principal London opticians, with their approximate magnifying powers and angles of aperture, may assist the student in selecting a glass suitable for the object to be examined. It must be borne in mind that the powers given are those of the lenses when used upon the stands of their respective makers; the length of the body materially influences the power of the combination, as will be seen by the table for the use of the draw-tube given in Messrs. Beck's list:—

R. and J. BECK.

Focal Length.		Linear Magnifying Power (nearly) with Eye-Pieces. 1	2	3	4	5	Angle of Aperture about
3 inches	Draw-tube closed	12	20	40	48	74	12 degs.
	Do. if drawn out, add for each inch	2	4	6	7	10	
2 ,,	Draw-tube closed	20	38	70	85	130	18 ,,
	Do. if drawn out, add for each inch.. ..	4	6	8	12	15	
$1\frac{1}{2}$,,	Draw-tube closed	30	56	100	120	190	23 ,,
	Do. if drawn out, add for each inch	5	7	12	15	22	
$\frac{2}{3}$,,	Draw-tube closed	70	120	220	270	410	32 ,,
	Do. if drawn out, add for each inch	8	14	25	27	48	
$\frac{1}{10}$,,	Draw-tube closed	120	210	370	460	710	55 ,,
	Do. if drawn out, add for each inch	14	24	34	46	70	
$\frac{4}{10}$,,	Draw-tube closed	146	255	450	560	890	90 ,,
	Do. if drawn out, add for each inch	18	32	48	60	80	
$\frac{1}{4}$,,	Draw-tube closed	200	340	590	720	1120	75 ,,
	Do. if drawn out, add for each inch.. ..	24	42	63	85	120	
$\frac{1}{5}$,,	Draw-tube closed	225	400	700	860	1450	85 ,,
	Do. if drawn out, add for each inch	18	35	60	80	130	
$\frac{1}{5}$,,	Draw-tube closed	225	400	700	860	1450	100 ,,
	Do. if drawn out, add for each inch	18	35	60	80	130	
$\frac{1}{8}$,,	Draw-tube closed	500	870	1500	1850	2800	120 ,,
	Do. if drawn out, add for each inch	60	100	180	190	370	
$\frac{1}{20}$,,	Draw-tube closed	900	1570	2750	3450	4950	140 ,,
	Do. if drawn out, add for each inch	80	150	300	350	900	

THOMAS ROSS.

Object Glasses.	Angular Aperture.	Magnifying Powers with the various Eye-Pieces.					
		A	B	C	D	E	F
5 inches	7 degs.	8	13	24	36	52	72
4 ,,	9 ,,	10	16	30	45	65	90
3 ,,	12 ,,	13	20	35	56	84	112
2 ,,	15 ,,	20	32	55	90	135	180
1½ ,,	20 ,,	25	40	70	112	168	224
1 ,,	15 ,,	37	60	105	170	255	340
1 ,,	25 ,,	37	60	105	170	255	340
⅔ ,,	35 ,,	60	100	145	270	405	540
½ ,,	90 ,,	95	153	265	420	630	840
4/10 ,,	110 ,,	140	220	370	650	975	1300
¼ ,,	100 ,,	195	310	540	850	1275	1700
¼ ,,	140 ,,	195	310	540	850	1275	1700
1/6 ,,	140 ,,	320	510	700	910	1360	1820
⅛ ,,	140 ,,	420	670	900	1200	1800	2400
1/12 ,,	170 ,,	600	870	1200	2000	3000	4000

POWELL AND LEALAND.

Object Glasses.	Angular Aperture.	Magnifying Power with the various Eye-Pieces.				
		1	2	3	4	5
2 inches	14 degrees	25	37	50	100	150
1½ ,,	20 ,,	37	56	74	150	220
1 ,,	30 ,,	50	74	100	200	300
⅔ ,,	32 ,,	75	111	150	300	450
½ ,,	70 ,,	100	148	200	400	600
4/10 ,,	80 ,,	125	187	250	500	750
¼ ,,	95 ,,	200	296	400	800	1200
¼ ,,	130 ,,	—	—	—	—	—
¼ ,,	145 ,,	—	—	—	—	—
⅕ ,,	100 ,,	250	370	500	1000	1500
⅛ ,,	140 ,,	400	592	800	1600	2400
1/12 ,,	145 ,,	600	888	1200	2400	3600
1/16 ,,	175 ,,	800	1184	1600	3200	4800
1/25 ,,	160 ,,	1250	1850	2500	5000	7500
1/50 ,,	150 ,,	2500	3700	5000	10000	15000

The screws cut upon the nozzles of microscopes, and upon object-glasses, are now common among English opticians, so that the objectives may be attached to any stand at pleasure.

The following symbols will be employed to indicate the apparatus to be used.

Object-Glasses—

4 in. or 3	in.	.. ..	O3
2 ,,	$1\frac{1}{2}$,,	.. ..	O2
1 ,,	$\frac{8}{8}$,,	.. ..	O1
$\frac{1}{2}$,,	$\frac{4}{10}$,,	.. ..	O$\frac{1}{2}$
$\frac{1}{4}$,,	$\frac{1}{8}$,,	.. ..	O$\frac{1}{4}$

Higher powers, O, with the fraction indicating the nominal focal length.

Eye-Pieces.—When no symbol is used, the lowest power, viz., No. 1, or A, is supposed; medium power, E 2; deeper, E 3; return from deep eye-piece to one of lower power, E.

The binocular prism is supposed to be employed in general; when it is to be withdrawn, and the instrument rendered monocular, M is used; the return to the binocular is indicated by B.

The illuminating apparatus first mentioned is that to be used if possible; that following, between brackets, may be used as a substitute.

The apparatus and materials constantly required, besides the microscope, are—

Lamp (pp. 23—27).—A glass stage-plate; easily made by attaching a narrow slip of glass, with marine glue (pp. 42—44), to a glass plate of convenient dimensions, so as to form a ledge, and prevent objects slipping off when the stage is inclined.

Some 3 × 1 slides; a small stock of thin cover glass, in squares and circles; forceps; needles mounted in handles (p. 49); a few pipettes (p. 38), and some blotting-paper; a small quantity of alcohol and turpentine; and also a supply of water should be at hand.

The following books, being often referred to, will be quoted with abbreviated titles:—

Carpenter.—"The Microscope and its Revelations," by W. B. Carpenter, M.D. (4th edition, 1868.)

Beale.—"How to Work with the Microscope," by Dr. L. S. Beale, F.R.S. (1868.)

Hassall.—"Adulterations Detected," by A. H. Hassall, M.D.

Lesson I. On the Use of the Condensing Lens and Mirror.

Material for Examination—White Blotting-Paper.

Arrange the microscope at a comfortable inclination, and adjust the draw-tubes of the eye-pieces to suit the distance between the eyes. Screw on the objective, O1; in doing this, hold the glass within the nozzle of the microscope with the first and second fingers of the left hand, while it is screwed in with the finger and thumb of the right. Do not leave go with the left hand until the screws have good hold; observe the same precaution in unscrewing; never risk the fall of an object-glass.

Tear with the forceps (not cut) a minute fragment from the edge of a piece of blotting-paper;

place it upon the glass stage-plate, and bring it, as nearly as can be judged, under the centre of the object-glass, which should be well raised above the stage. Place the lamp on the left of the microscope, at a height about half way between the stage and eye-piece, and direct the light upon the paper with the condensing lens (p. 27). Bring the object-glass down, by means of the coarse adjustment, nearly to the working distance of the objective; this is always considerably shorter than the nominal focal length; with O1 it may be a little more than half an inch. After a little practice, the student will learn the proper distance for each glass; until this is acquired, it is best to proceed cautiously, to avoid injury to the object, especially when high powers are used.

Now look through the instrument; adjust the position of the object, with the fingers or stage movements, until it occupies the centre of the field; bring it accurately into focus with the coarse adjustment; and alter the position of the condensing lens and of the lamp, if necessary, so as to obtain the most perfect illumination.

The paper will be found to consist of interlaced fibres, which are seen to the best advantage at the edges, where they are frayed out: hence the direction to tear. This applies in numerous cases, a laceration or fracture sometimes revealing points of structure in a manner not easily demonstrated by other means.

When the object has been fully examined, remove

the condenser, open the large aperture in the wheel of diaphragms beneath the stage, lower the lamp upon its stem into a convenient position for lighting the concave mirror, and direct the convergent pencil upon the object. It will be found that the view now obtained is in every respect inferior to that by reflected light; this is owing, partly to the opacity of the paper, and partly to the different densities of the object and of the medium in which it is viewed. If a higher power, O¼,M, is used, the result will be much worse; this kind of view is that obtained by beginners, who usually try to examine every object by transmitted light, and but rarely use other and better means of illumination. Change the power to O1, B; place a drop of water on the object with A PIPETTE [*or the tip of the finger*]; cover with a thin glass; absorb any surplus moisture with blotting-paper; replace the slide on the stage; and adjust the focus. The confused appearance of the edges has now disappeared, and the light to some extent penetrates the central portions of the object. With the binocular, the full light from the mirror will be found to produce an unpleasant glare, and the *white cloud* illumination (p. 106) may be substituted with advantage. Still, little beyond the fibres at and near the edges can be well made out. Remove the slide from the stage; take off the cover, and with a pair of mounted needles tear up and spread out the moistened paper; replace the cover, and examine as before. All the structure will now, probably, be seen; if not, tear the object up still more, until the

result is satisfactory. Higher powers may now be used with advantage, taking care to make the requisite correction for the aberration caused by the cover-glass (p. 17), should the objective be provided with the proper adjustment. With the glasses O½, ·O¼, and higher powers, it will be desirable to employ the fine adjustment in completing the focussing, and during the observation. Until the beginner has had some experience, it will be best to use O½, in preference to a higher power, as the risk of damaging the object, or object-glass, is lessened; after a time, the use of glasses of short working distance will become easy. In removing a slide from the stage when a high power is employed, raise the body to some distance, to prevent accidental contact with the front lens, as it might be scratched or otherwise injured.

Try the effect of viewing some more torn up fragments in other media, such as oil, turpentine, or glycerine. Mount a specimen in balsam (p. 61), taking care that the paper has been well saturated with turpentine, to remove air bubbles.

These experiments may be repeated with other kinds of paper, and their different degrees of compactness noticed. The determination of the material of which the paper is composed had better be deferred until Lesson VI. has been studied.

Arrange the microscope and lamp for the use of the condensing lens; as before, use O1, B; make a few marks, with a soft black-lead pencil, on a piece of blotting-paper, and notice the disposition of the

particles of plumbago among the fibres. Examine ink marks; printing from plate (a visiting card will do); likewise specimens of surface-printing, as wood engraving or type, and also lithographs. Notice the varying manner in which the ink is distributed.

Repeat the experiments with the light on the right hand, and also in front. Although it is most convenient to place the lamp on the left, because it is out of the way of the right hand moving and adjusting the object in the stage, yet it may sometimes be required to place the light elsewhere; and the student should be able to work with it in any situation. Practice by daylight should not be neglected whenever opportunities offer.

Try, also, the effect of using different eye-pieces. When a complete series of objectives is not at hand, an awkward interval of magnifying power may often be thus filled up (see Tables, pp. 179, 180). In drawing, it is often useful to make the object fill the field; this can generally be done by a suitable change of eye-piece.

Lesson II.

Material for Examination—Dirt from Sponges.

This can be obtained in any quantity from dealers. It accumulates at the bottom of the boxes in which sponge is imported.

Arrange the microscope as in the former lesson, O2, Illuminator. Parabolic Lieberkuhn or [*Condensing-Lens*].—If artificial light is used, render the

rays parallel (p. 94) before they are reflected from the lieberkuhn.

Spread a small portion of the substance over the stage-plate.

The specimen will most likely be found to consist chiefly of sand, which prevents a good view of the other substances in it being obtained, although, here and there, some objects may be seen. The sand may be removed by sifting through a piece of wire-gauze, of about 40—50 threads to the inch; or a series of sieves may be used, if it is wished to carry out the sorting to a greater extent. Examine some of the coarse residue as before. The principal contents will be coarse sand and fragments of rock, fibre, abraded splinters of wood, seaweed, fragments of *Echinus* spines, skeletons of various *Hydrozoa* and *Polyzoa* (vulg., *Zoophytes*), sponge, spicules (Pl. 2, figs. 7—11), and shells (Pl. 2, figs. 1—6).

Separate the shells and other objects that may be required for further study; this may be done by picking them up with a small camel-hair pencil, moistened and drawn to a point. Small pill-boxes or homœopathic-bottles make convenient receptacles for keeping these objects in, when sorted. A pocket-lens mounted on a stand, or a watchmaker's glass will afford sufficient magnifying power. If the light is concentrated upon the substance to be examined with the condensing-lens, and black paper used to spread the sand on, a great deal may be done without using the glass at all. For dissecting and more delicate operations of this kind, Beck's 3-inch

binocular magnifier will be found useful: it is, in effect, a pair of achromatic spectacles of considerable power, and fatigues the eyes less in prolonged operations than the use of a single lens. A more complete binocular dissecting microscope is described in "Carpenter," p. 54.

Select some of the shells (Pl. 2, fig. 1—6) resembling small nautili (*Foraminiferæ*), and make arrangements for examining them in varied positions with DISC-HOLDER (p. 53) or [*stage-forceps*]. Observe the peculiar structure of the part where the mouth of an ordinary univalve-shell (*Gasteropoda*) usually is (Pl. 2, fig. 1 *a*), closed with a perforated plate, instead of being open. Also, in some species, perforations will be observed on the sides of the shells: hence the name of the group *Foraminiferæ*. Mount some of the shells dry in various positions (taking especial care that the mouth is well displayed), label, and preserve for reference.

Bed some of the shells in balsam (p. 64), and grind away the surface so as to expose the interior; carefully polish, and remove the balsam. This process will reveal the chambered internal structure, which varies extremely in different species. An increase of power may now be used with advantage (O1, or O¼ if the illuminator for this higher objective is accessible). With such augmented power, the minute shell-structure may be observed; but this can be accomplished more readily by grinding a thin section, which will admit of examination with higher powers and the paraboloid or

achromatic condenser. These thin sections can be ground by a process devised by Dr. Wallich (*Ann. Nat. Hist.*, July, 1861; also "Carpenter," p. 192, note). The shell is to be fastened to a thin plate of mica, in the first instance, and this, with the shell upwards, is to be cemented to the plate of glass on which it is held during the process. One side is ground and polished in the usual manner. The slide is then warmed, which permits the removal of the mica plate with the half-finished section attached. The shell is then cemented by its polished side to another grinding-plate, and completed in the usual manner. The plate of mica is easily ground away, and offers no impediment to the cutting of the shell. The resulting section is to be mounted, either dry or in balsam, as circumstances may require.

Foraminiferæ and other shells abound in deep-sea soundings. As usually obtained from this source, they are mixed with the tallow placed at the bottom of the lead to bring up the sample: this grease must be removed by solution in benzol. *Foraminiferæ* and other fossils may be separated from chalk by processes described in Lesson III.

For further information respecting the *Foraminiferæ*, see art. *Foraminiferæ*, "Micrographic Dictionary," p. 292; "Carpenter." pp. 482—523; Greene's "Manual of the Protozoa;" Williamson and Carpenter's Monographs (Ray Society).

Lesson III.

Specimens Required—Flour, Starch (Arrow-root, Potato-starch, or Brown and Polson's Corn Flour), Chalk (in Lump, not Whiting or Washed Chalk), Powdered Lump-Sugar, and Common Table-Salt.*

Examine by placing a minute quantity of each of these white powders on the stage-plate, and examine with O1, by reflected light, as in preceding lessons. Notice the different appearances of each. The flour will be found to contain numerous rounded, glittering bodies (starch granules), mixed up with a quantity of matter not easily defined with the power employed. The starch consists entirely of these shining substances, which, in the larger kinds, as "Tous-les-mois" (Pl. 3, fig. 1), cause a distinct glittering appearance without any optical aid, if examined in a good light. The chalk is apparently structureless. The sugar and salt exhibit numerous crystals, more or less broken.

The student will do well to examine the solubility of these substances, by shaking a little of each in a test-tube, with water. Small portions should also be heated to redness, on a slip of platinum foil, in the flame of a spirit-lamp. The flour and starch will be carbonised and burnt to an ash, if the heat is long continued. The chalk will still remain white. The sugar will melt, and then carbonise. The salt

* This is a very cleanly prepared *maize*-starch (Pl. 3, fig. 5), which may be used for nearly every purpose where arrow-root is required. It would be well if manufacturers would call things by their right names. The term "flour" is likely to mislead; it means something quite different. Corn-starch or maize-starch would be more suitable.

will decrepitate or crackle, and bound off the platinum.

These simple chemical examinations should not be neglected by the microscopist, especially when examining unknown substances. Some skill in the use of the blowpipe may occasionally be of service. Solubility of a substance in water or other fluids may be tested under the microscope, and with the advantage that very small quantities are sufficient for experiment. Other reagents may also be employed. "Beale," p. 201.

Flour and Starch.—Place a little of the starch and flour on separate slides, with a drop of water; stir up with the point of a knife or needle, to diffuse the particles; cover with thin glass, and view with same power, first with dark-field illumination, and afterwards by transmitted light. Then use O¼M by transmitted light. The flour will be seen to consist of the before-mentioned rounded bodies, with a small admixture of fragments of membrane, cell wall, &c. These are best seen in meal made by crushing or grating a grain of corn, as flour in general is too finely sifted to contain much of these textures. The slide of starch will exhibit the same rounded bodies, starch granules. They are best studied in a large-grained kind, such as *Tous-les-mois** (Pl. 3, fig. 1), the product of *Canna edulis*. With O¼M and transmitted light, a number of concentric rings will be seen, surrounding a spot known as the *hilum*. Microscopists differ respecting

* *Tous-les-mois* can be obtained of Messrs. Fortnum and Mason; also *genuine* arrow-root and other materials, which can be depended upon for use as standard samples.

the nature of these markings (see article, *Starch*, "Micrographic Dictionary," p. 657; "Carpenter," p. 399). Examine with *polariscope* O1, and, if possible, with higher powers. Notice the characteristic black cross, having its centre at the hilum. In oat-starch (Pl. 3, fig. 4) the black cross is wanting, the grains are polygonal, and clustered in rounded masses. Test the contents of the slides with a solution of iodine in water, made by placing a small crystal in distilled water. When it has acquired a straw colour, it will be of sufficient strength; only a minute quantity will be dissolved. A small drop of this reagent is to be placed at the edge of the cover with a pointed pipette, or, better, with one of the test-bottles with perforated conical stoppers. When the iodine reaches the starch granules, they will be stained of a violet colour. This and the polarisation test will readily distinguish starch granules from other round bodies. A series of starches from various plants should be mounted, and kept for comparison. Two slides of each should be prepared, one dry, the other in balsam for examination with the polariscope. When starch is mounted in balsam, care should be taken to employ as little heat as possible. Starch granules are not well preserved in fluids. Starch may be separated from flour by making it into a stiff paste, tying it in a muslin bag, and kneading in water. The gluten will be left in the bag, and the starch will fall to the bottom of the vessel, and can be cleaned by washing and decantation of the super-

natant fluid. Roots, &c. (as potatoes and carrots), can be crushed or grated, and the starch washed out, cleaned, and collected. Starch may be viewed *in situ* by cutting thin sections of potato. These may be dried by the ether process (p. 58), and some mounted dry, and others transferred to benzol, and then mounted in balsam.

Starches from various sources, and the structure of wheat, barley, and other kinds of grain, are accurately figured in "Hassall," pp. 242—256 and 314—321; see also Plate 3, figs. 1—6.

Dr. Letheby, in his "Lectures on Food," remarks "that although all starches and arrowroots have the same chemical composition and nutritive value, yet they are very different in their digestibility, the true arrowroots of the West Indies often remaining on the stomach of an invalid when the others would be rejected." Hence the importance of distinguishing the starches from various plants by means of the microscope. True West India arrowroot is represented (Pl. 3, fig. 2).

The student should make accurate outline-sketches of all the starches examined, with the camera-lucida or tinted reflector, selecting, in each specimen, the largest and smallest granules, and also some of intermediate size. A scale should be drawn on the paper from the micrometer. The shape and dimensions of starch granules and other similar objects are readily compared from such drawings, and with far greater facility than from lists of micrometric figures.

Chalk.—Scrape a small portion of the chalk upon a slide. Place upon it a drop of water, stir it up, allow the larger particles to subside, and then gently tilt the slide, so that the water may run down, and carry with it the lighter particles. Absorb the surplus wet with blotting-paper, dry cautiously over the lamp-chimney, and mount in balsam.

Examine with O½, or [O1, E2 or 3] black-field illumination, PARABOLA or [*spotted-lens*]. If the preparation has been successful, *Foraminiferæ* may be distinguished among some of the particles. It is well to make two or three preparations, in case of failure.

To obtain the shells, sponge-spicules, &c., separately, it will be necessary to break up the chalk. This is best effected by boiling in a solution of sulphate of soda, made strong enough to crystallise on cooling: on this taking place, the chalk will be found to be disintegrated (Quekett's "Lectures on Histology," vol. ii., p. 80). Sufficient water should then be added to dissolve the crystals, the mixture agitated, and the chalk allowed to settle. The fluid should be decanted, the vessel again filled up with water, and decantation repeated before the finer particles have subsided. By continuing this process, if carefully managed, the shells will be obtained, eventually, nearly or quite clean. The washings should be allowed to settle, and be examined with the microscope, to ascertain whether they contain any of the smaller fossils. The shells may be mounted dry or in balsam. The result will vary

according to the locality from which the chalk was obtained.

Another very efficient process, by Mr. E. H. Robertson, will be found in *Science Gossip*, vol. iii., p. 36.

If the sponge-spicules and siliceous fossils only are required, they can be obtained by dissolving the chalk in dilute hydrochloric acid.

The coarse matter left after chalk has been washed for the purpose of making whiting is, when it can be procured, a good material to operate upon, as it is much richer in minute fossils, which are left in the heavier portions of the chalk.

The *Polycystinæ* (Pl. 2, figs. 12—14) may be obtained from the "Barbadoes-earth," by a process fully described by S. Furlong, *Quarterly Microscopical Journal*, Jan., 1861; also quoted by Davies, in "Mounting Microscopic Objects," p. 64.

Sugar and Salt.—The preliminary examination has already shown that these two substances differ materially in appearance from the others with which they were compared. While they exhibited none of the organised structure of the flour and starch, yet the difference between them and the chalk was very marked. They presented, when not too much crushed, traces of a certain regularity of form, which was entirely absent in the latter mineral. The condition of both the sugar and salt was very unfavourable for the study of these regular forms, which are known as crystalline. For further examination, it will be necessary to procure uninjured specimens.

Well-formed crystals may generally be found in most samples of good moist-sugar: a few of these are to be mounted in balsam, for examination. Sugar is rather difficult to crystallise in the small way, the general result being an amorphous film on the slide. For a very full account of sugar, see "Hassall," pp. 181—198.

Crystals of salt are easily obtained. Make a strong solution in distilled water, by boiling in a test-tube, and filter while hot. A drop of this fluid, placed upon a slide, will soon deposit a number of cubic crystals. These and the sugar-crystals may be viewed with a low power, O2, and dark-field illumination, by means of the PARABOLIC REFLECTOR or [*spotted lens*]. This mode of lighting is very useful in such examinations, as it aids considerably in estimating solidity. Beyond regular mathematical form, no structure is to be observed in these bodies. *Polarised light*, however, renders certain optical peculiarities apparent.

Arrange the microscope for the use of the polariscope: it will then be seen that the crystals of salt are not at all affected by the altered illumination, and this is the case with all crystals belonging to the cubic system: crystals of potash-alum will supply another example. Let the sugar now be examined in the same way: it will be found, upon rotating the analyser or polariser, that they either become coloured or, when the field is darkened, remain luminous. If the thickness of the crystals is not adapted to produce colour, the use of a suitable

selenite film will assist in obtaining it. It is here evident that polarised light reveals something which we should not be aware of without its aid: it supplies the means of determining whether a crystal possesses the property of double refraction or not.

The forms and colours of many crystals are extremely beautiful, and a collection is very easily made. As a long list will be found in "Carpenter," p. 773, only a few salts will be mentioned here.

Make a hot saturated solution of sulphate of copper. If a drop of this warm solution is placed upon a slip of glass, and examined at once,* long crystals, with sloping ends like a turner's chisel, will be seen shooting out from the edge, which will eventually cover the centre. If a small quantity of nitrous ether be added to the solution, a number of the crystals will be obtained in the form of separate rhomboids, which will shine like richly-coloured gems on the black field of the polarising microscope. Both slides, when dry, should be mounted in balsam, and labelled.

Some curious phenomena attending the crystallisation of sulphate of copper are described by Mr. R. Thomas in the *Quarterly Microscopical Journal* (1866, p. 177). An abstract of the paper, with figures, will be found in "Beale," p. 214.

The crystals of salicine are very easily made, and are very good examples of radiating crystals. A

* For this purpose, the microscope must be placed vertically, to prevent the fluid running off the slide, as the observation is best made without a cover. The instrument should only be used in this position when absolutely necessary, as it is uncomfortable and inconvenient.

saturated solution in distilled water is to be made, and a drop, placed on a carefully-cleaned slide, is to be evaporated over the lamp until it dries into an amorphous mass. Upon cooling, a number of circular groups of crystals will generally be formed; this may be aided by breathing on the slide, the moisture often inducing the formation of the crystals. When sufficiently developed, the process should be stopped, by gently heating over the lamp-chimney, and mounting at once in balsam.

An account of the mode of making the beautiful flower-like crystals of sulphate of copper and magnesia is given in "Mounting Microscopic Objects," by T. Davies, p. 76.

Lesson IV.

Structure of Wood.

With the point of a sharp knife, split, *not cut*, thin splinters from a lucifer match or piece of deal. Suitable fragments may often be found at the bottom of a box of matches. Examine with O1; illuminate with Parabolic Lieberkuhn or [*condensing lens*], using Disc-Holder or [*stage forceps*] as a support. The splinter will exhibit a fibrous structure, varying in character according to the direction of the split. The appearance presented in Plate 1 is obtained when the cleavage follows one of the lines radiating from the centre of the stem, and gives a better view of the elementary tissues of which wood is composed

than any other single section. The simplest structure in this specimen is the cellular tissue seen in the figure crossing the woody fibres; these lines of cells run from the centre of the stem to its circumference, among the fibres and ducts, keeping up a communication between the centre and the growing portion between the wood and the bark, known as the *cambium layer*. The sides of the woody fibres are, in deal, covered with rows of dots, which are characteristic of the *Coniferæ*, although they are found in the woody tissues of some few other trees. To see these well, a higher power will be required, O½, and PARABOLIC, or [*spherical lieberkuhn*], and to secure the most favourable position for observation the disc-holder will be found convenient.

To thoroughly investigate the structure of wood, three sections are necessary, one across the stem (Pl. 4, figs. 1, 2, 5) and two in a longitudinal direction (Pl. 4, figs. 3, 4, 6). For the purpose of study, where large and fine specimens are not required, the use of a section machine may be dispensed with, as small sections in any direction may easily be cut with a sharp knife or razor.

The *transverse section* (Pl. 4, fig. 2) shows the general arrangement of the tissues composing the stem, consisting of a concentric arrangement of fibres and vessels, of which the cut ends only are seen in this section; the concentric rings represent periods of growth, and usually, but not always, correspond with the number of years the stem has been forming; the *medullary* rays are seen running

from the pith in the centre to the circumference; their cut ends are seen in fig. 4 and their sides in Plate 1 and Plate 4, fig. 3 *c*—they are developed to an enormous extent in the Clematis (Pl. 4, fig. 1 *c*), where their grouping in masses gives a marked character to the transverse section.

The other two sections are cut, one parallel to the medullary ray (Pl. 4, fig. 3) and the other across it (Pl. 4, fig. 4). The former corresponds with the splinter figured in Plate 1. The first, or *radial section*, exhibits the sides of the medullary rays; the second, *tangential section*, their cut ends; these are very conspicuous in mahogany.

The structure of the stem of endogenous plants differs considerably from that of exogens, just described; in these, there is no marked distinction between wood and bark (Pl. 4, fig. 5)—the rings of annual growth and the medullary rays are wanting, so that a single longitudinal section (Pl. 4, fig. 6) only is required, instead of the two needed to demonstrate the structure of an exogen (a section of cane will supply a good example). For the histology of plants, see Bentley's "Manual of Botany," Book I. There are many very accurate figures of vegetable tissues throughout Hassall. The knowledge of the minute structure of plants is of the greatest use to the analytical microscopist, as it is by this means alone that mixtures of vegetable powders can be detected. Full details are given in Hassall.

Sections of woods, such as ebony, box, and some others, which are too hard to be cut in the usual

manner, may be obtained by grinding, as in the case of bone; this process must also be adopted with cellular tissue, when hardened by deposits of sclerogen, as cherry and plum stones, ivory nuts, cocoanut shell, and many other hard substances. Soft substances, as leaves, may be cut by being pressed between two pieces of cork, which are sliced with it. Cellular tissue like that of the common rush, which yields so much to the knife that it is pressed aside instead of being cut, should be saturated with melted wax before attempting to make a section; this can be removed from the thin slices with benzol.

Lesson V.

Aquatic Examinations.

The results of aquatic collecting will require a somewhat different treatment from that recommended in the preceding lessons. Owing to the density of the medium in which the objects are viewed, and the generally diaphanous nature of the organisms themselves, comparatively little use can be made of reflected light as a means of illumination; its employment is, therefore, rather the exception than the rule.

An account of the varied modes of collecting objects of this kind, and their habitats, would almost occupy a volume. For obtaining fresh-water specimens, advantage may be taken of the excursions of the various London and provincial societies. The

Quekett Microscopical Club arranges a series of excursions, which take place every fortnight during the summer months; and, as experienced naturalists always accompany these expeditions, the student may derive much practical instruction in the way of collecting and identifying specimens. The microscope should always accompany the student to the sea-side during a temporary residence, and it is well, if possible, to take the usual working instrument, well equipped with objectives and apparatus, and not some small contrivance which has nothing to recommend it but portability. The following works also contain useful information on the subject of marine and fresh-water collecting:—"Handy-Book of Algæ, &c.," Rev. W. W. Spicer; "Beale," p. 146; "The Aquarium, Devonshire Coast, Tenby, &c.," P. H. Gosse; "Seaside Studies," G. H. Lewes; "Marvels of Pond Life," H. J. Slack; "History of Infusoria," A. Pritchard. See also list of microscopical works in "Beale," p. 364.

The preliminary examination of a quantity of aquatic material is generally most conveniently done in a large trough (Fig. 15, p. 45), with a low power, O3,* and *dark-field illumination*, mirror turned aside, or *long-focus spotted-lens;* the paraboloid has too short a focus for this purpose.

A good diagnosis can often be made by examination in the bottle or tube in which the collection is

* Ross's 4-inch objective is very suitable for this kind of work; it defines well, bears a considerable amount of eye-piece power, will take in an object of about 0·4 inch diameter, and is low in price.

brought home, with the pocket-lens. Many of the larger animals and plants can be distinguished with this low power, and those too small to be distinctly made out can often be identified by a trained eye. Objects in water may be very conveniently examined out of doors with the pocket-lens, if placed between two small pieces of glass (a 3×1 slide cut in half, and the sharp edges smoothed with a corundum rubber, answers well): these can be kept in the waistcoat pocket, ready for use.

Portions required for more minute examination, if on plants, may be detached with the scissors or forceps. Free-swimming animals, and plants, or deposits, may be taken up with a suitable pipette, by closing the upper end with the finger, and bringing the other extremity over the object to be secured. The finger is then to be removed; and the water rushes in, carrying the object with it. The finger is again applied, to close the top of the tube, which is then lifted out of the water, and the object transferred to a slide, cell, or other convenient vessel.

If the object is very thin, a common slide, covered with a piece of thin glass, will serve for the examination with a tolerably high power. Should the object be liable to injury from the pressure of the cover, a cell may be used, or a hair placed between the thin glass and the slide. In all cases in which the object is required to be kept for some days, the growing-slide (Fig. 16, p. 46) should be used: some of these may conveniently be made with cells attached. The thin trough (Fig. 14,

p. 44) may sometimes be useful. All these contrivances permit the employment of the parabaloid for dark-field illumination, and also the achromatic condenser. The live-box supplied with most microscopes is sometimes useful, but has the disadvantage, from the height it raises the object above the stage, of preventing the employment of any sub-stage illuminator but the mirror.

It is frequently necessary to subject the substance under examination to pressure. For this purpose, an instrument known as a *compressorium* is necessary, two of which, more completely fulfilling the requirements of the microscopist than older contrivances, are the invention of the late Richard Beck (*Quarterly Microscopical Journal*, vol. xii., p. 4); we are also indebted to him for a live-trap for confining small active animals within the field of the microscope, without compressing them or otherwise restraining their movements (*Quarterly Microscopical Journal*, vol. xiii., p. 113).

The habits of marine or fresh-water animals may be watched in aquaria, which need not of necessity be expensive: basins and glass jars answer the purpose extremely well. The marine aquarium should always be carefully examined after the introduction of fresh specimens of seaweed, as they usually bring in with them large numbers of minute organisms.

The author, instead of throwing away the results of fresh-water collection when done with, places them in a tank in the garden, used for growing aquatic plants, which, although only containing

about 200 gallons of water, always yields a rich supply of microscopic objects, most of which regularly breed and appear from year to year.

Some of the commoner microscopic inhabitants of fresh and salt water are represented in Plates 5 and 6.

Lesson VI.

Fibres used in the Manufacture of Clothing, and Analysis of Textile Fabrics.

The materials of textile manufactures may be divided into four classes, two of which are derived from the vegetable and two from the animal kingdom.

The vegetable fibres consist either of hairs or liber cells, a tissue resembling woody fibre.

Of hairs, only those covering the seeds of several species of *Gossypium* (a genus of malvaceous plants) are used in commerce, and are known as *cotton* (Pl. 7, fig. 4).

The liber cells are supplied from many sources, and are used for a great variety of purposes, every kind of fabric, from fine linen to cordage, being made from them.

Familiar examples are flax (*Linum usatissimum*, Pl. 7, fig. 5), jute (*Corchorus capsularis*, Pl. 7, fig. 2), hemp (*Cannabis sativa*) ,China-grass or rhea (*Bœhmeria nivea*).

The animal materials consist of silk (Pl. 3, fig. 9, and Pl. 7, fig. 3), an albuminous fibre produced by various caterpillars.

The remaining class comprises the hairs of those animals which are capable of being either spun or felted—such as wool (Pl. 7, fig. 1, and Pl. 3, fig. 7) and its varieties, as alpaca, &c., hairs of rabbit, beaver, &c.

Specimens Required.—Fibres of cotton, flax, hemp, silk, and wool; pieces of calico, muslin, linen, silk, flannel or blanket, and any other woven fabrics and threads procurable; also hairs of various animals.

Examine fibres of cotton, flax, hemp, silk, and wool, as described in Lessons I. and II., with O1 or O½, on stage-plate, by reflected light.

Notice the differences of structure. *Cotton* consists of *flattened*, *twisted fibres* (Pl. 7, fig. 4). *Flax* and *hemp* are *rounded* (Pl. 7, fig. 5), with more or less apparent *transverse markings*. *Silk* is conspicuous for the *absence of all structural peculiarities* (Pl. 7, fig. 3). *Wool* exhibits a *circular fibre*, with *delicate markings* (Pl. 7, fig. 1).

It will be seen that the four classes of fibres have all well-marked characters, and can be readily distinguished from each other under the microscope.

Mount specimens of all the fibres collected, by dry process (p. 55), taking care, as fibrous tissues are very hygroscopic, that they are properly dried. As they will bear a heat not exceeding that of boiling water without injury, the ether process will not be required. Label, and preserve for future reference. Place, also, a small portion of the fibres of cotton, flax, and hemp in separate bottles, with saturated solution of chloride of calcium; leave

them to soak for a few days, and then mount in same fluid, taking the precaution to separate the fibres by tearing them apart with needles, so that the single fibres may be well displayed before closing the cell. The silk and wool should be mounted dry, and also in balsam, with as little heat as possible, if transparent specimens are required.

As the mountings in chloride of calcium will be some days in hand, unless the air-pump is used, prepare portions of cotton and flax, on slides, with turpentine, which will render the fibres transparent; and examine with a power of not less than O½ (O¼ will be better), with polarised light, using achromatic condenser and eye-piece analyser (p. 136). If the condenser is not accessible, the intensity of the illumination may be greatly increased by concentrating the light of the lamp on the concave mirror with the condensing-lens.

The *cotton* will display *more or less colour*, indicating doubly-refractive properties, but *no very marked structural peculiarities* (pl. 7, fig. 4). The *flax* will show *a vast amount of structure* (pl. 7, fig. 5). The transverse markings seen by reflected light will become more conspicuous, and other markings of a more or less spiral nature will, with proper adjustment of the selenites (p. 140), be rendered visible. These consist of thickenings of the cell wall, known as secondary deposits, and are easily seen by polarised light, owing to their doubly-refractive power differing from that of the thinner portions of the tissue; while by ordinary transmitted

light, they would have been nearly invisible, owing to their transparency. It is much easier to distinguish the fibres of cotton and flax in a mixed fabric by observations with polarised light than by any other means. A power of O1 is quite sufficient when merely the presence of cotton in a flax fabric has to be determined.

A careful series of observations on liber cells is much wanted. At present, it is difficult to distinguish between flax and hemp, and other fibres of the same class, so that they might be detected with certainty in mixed fabrics. The chief impediment consists in the very close resemblance of all these fibres to each other. It is, in general, much easier to distinguish them in mass, by various peculiarities of colour, texture, &c., than by the most careful microscopical examination of single fibres.

The action of dyes might reveal some peculiarities connected with these tissues. Experiments on cotton have been tried by the late Mr. W. Crum, F.R.S. Transverse sections* have been examined by a Continental observer, and, although somewhat difficult to obtain, might be studied with advantage. The whole subject is much in need of investigation.

Woody fibres are used occasionally for purposes of adulteration; an instance is mentioned under silk. A curious case came under the author's notice, in which cotton wick, intended for the manufacture

* Fibres, hairs, and other long thin substances of which sections are required should be made up into bundles with weak glue, and cut into thin slices with a sharp razor; the sections can be liberated by dissolving the gelatine in hot water.

of composite candles, was adulterated with a small quantity (about 5 per cent) of some undetermined woody fibre. Trivial as was the amount of this admixture, it entirely unfitted the wick for the purpose for which it was intended, causing it to remain unconsumed, and accumulate, instead of bending over to the outer part of the flame, and burning away.

For account of liber cells, see—Bentley's "Manual of Botany," p. 30; article, *Liber*, "Micrographic Dictionary," p. 417; *Science Gossip*, vol. ii., p. 10.

The length of cotton-fibre (*staple*) is determined by drawing out a tuft of the cotton repeatedly between the fingers, until the hairs are laid parallel, and then measuring the length of the tuft. This is the mode of measurement in use among cotton-brokers. An easy and accurate method of measuring single fibres of cotton had long been a desideratum in analytical operations. In 1862, Captain C. J. Mitchell, of the Government Central Museum, Madras, writes, respecting a process he had used for this purpose:—"It is exceedingly tedious, and very trying to both eyes and head." Shortly afterwards, the author endeavoured to measure single fibres by fixing them with gum upon a glass slide, making a drawing with the camera-lucida, and measuring the curved line so obtained with a map-measurer. The enlarged drawing was from 18 inches to 2 feet in length. The chief objection to this process was the amount of time occupied in the investigation, ordinary micrometrical operations not being applicable, on account of the great length of the fibres and the impossibility

of measuring them as straight lines; hence the necessity of making drawings, and following all the curves with the little measuring-wheel. A simple and accurate process has been invented by Mr. C. O'Neill, and is described by him in a communication to the Literary and Philosophical Society of Manchester "Memoirs," (1863—4, p. 389). The apparatus employed consists of a plate of glass, on which is ruled a scale 2 inches long, divided into tenths, a pair of fine forceps, and two camel-hair pencils. The scale is laid upon a piece of black cloth, and well lighted, by daylight or a lamp with condensing-lens. The fibres are selected, and held by the forceps, and, with one of the pencils, moistened in the mouth, pressed and drawn out on the glass plate; the forceps are then dropped, and the other pencil brought into use to lay out the fibre, the length of which is then read off. The operation requires considerable practice, but, when acquired, single fibres can be measured to 0·05 inch with sufficient rapidity for analytical purposes. As some cotton-fibres—such as Sea Island—reach the length of 2 inches, it is well to have the scale extended to 3 inches; this will also prevent the necessity of being careful about placing the fibre on the beginning of the scale, as there will be plenty of space. And it is convenient to have a scale of about the same length divided into millimetres for comparison with Continental observations. Mr. O'Neill gives the following results of some observations on the length of cotton-fibres :—

	Maximum. in.		Mean. in.		Minimum. in.
Sea Island	2·00	..	1·6800	..	1·35
Another sample	2·05	..	1·4440	..	1·10
Queensland	1·95	..	1·5010	..	1·10
Egyptian	1·55	..	1·2520	..	0·95
Pernambuco ..	1·50	..	1·6750	..	0·75
Surat	1·15	..	0·9425	..	0·75
Another sample	1·10	..	0·9250	..	0·55
Another sample	1·05	..	0·9050	..	0·70

In another communication (1862-3, p. 389), Mr. O'Neill describes an ingenious instrument for measuring the tensile-strength of fibres. The following are some of the mean breaking-weights of single cotton-fibres :—

	grs.
Sea Island	83·9
Another sample	90·0
Surat	105·8
Another sample	141·9
Egyptian	108·0
Another sample	127·0
Pernambuco	140·0

These determinations are of great value to the manufacturer. And those intending to make textile fabrics their study would do well to consult Mr. O'Neill's papers.

The amount of twisting in a thread is a very important element in the estimation of its strength. The famed Dacca muslins owe much of their superiority in lightness* and strength to the tightness of the twist in the delicate filaments of which they are composed. This has been determined by

A piece of fine Dacca muslin, 1 yard wide and 10 yards 12 inches long, weighed only 1565 grains (Dr. Watson; work cited, p. 75).

Dr. J. F. Watson, who gives the following as the average number of twists per inch in four samples of muslin:—French, 68·8; English, 56·6; Dacca, 110·1; Dacca (another sample), 80·7. The whole subject is carefully worked out by Dr. Watson in "The Textile Manufactures and Costumes of the People of India," pp. 59—74.

Cotton is mixed with other fibres legitimately in the well-known "union cloth," a compound of flax and cotton, and as an adulteration, with woollen fabrics, and in some specimens of lint.

Silk will be found to burn differently from the fibres of the two classes hitherto considered. It curls up, and ultimately fuses and burns, giving off the disagreeable odour common to animal tissues, as hair, wool, feathers, &c. The fibres depolarise light, giving more or less colour, but do not exhibit any structural peculiarities (Pl. 7, fig. 3). Silk is entirely dissolved when boiled in strong solutions of caustic potash or soda. If *cautiously* heated on a slide in a strong solution of soda, the fibres will be found to swell, and bulge out in parts (Pl. 3, figs. 9, 10).

Admixtures of other fibres with silk are easily detected, by the appearance of the unravelled threads, under the microscope. The material most commonly used to adulterate silk is jute (Pl. 7, fig. 2). The microscopical characters of this fibre are not of a very marked description. It is best distinguished by examining the residue under the microscope after the sample has been boiled in a strong caustic

alkaline solution. Specimens of silk, breaking and fraying when pressed into tight folds, may always be suspected of containing jute: the beautiful gloss of this fibre, when carefully prepared, is the reason of its selection as an adulterating material.

Wool.—As already observed, this fibre presents very marked structural peculiarities. In burning, the same phenomena are apparent as in the case of silk; it is also soluble in hot alkaline solutions. The histological nature of the surface-markings may be considered undetermined at present, the apparent imbrications being interpreted by some as scales; and in many hairs (those of some of the bats especially) this character is very marked (M. C. Cooke, *Transactions of the Quekett Microscopical Club*, vol. i., pp. 33 and 55, Plates 1, 2, and 3; article, *Hairs of Animals*, "Micrographic Dictionary," p. 330; "Carpenter," p. 704).

Two valuable communications on "Wool, Commercially and Microscopically Considered" were made by Mr. N. Burgess to the Quekett Microscopical Club. Unfortunately, only abstracts appear in the *Transactions* (vol. i., p. 23). In this paper some important points of microscopical structure, bearing upon the felting process, are noticed. It is shown that the felting qualities of wool depend upon the number of waves or curvatures in the length of a fibre, and not upon the apparent serrations or imbrications.

When heated on a slide with strong solution of soda, wool swells, the medulla or interior cellular

portion becomes more distinct, and the imbrications disappear, seeming to have unfolded (Pl. 3, figs. 7, 8).

Wool is mixed with other substances in the manufacture of fabrics generally with the view of improving the texture or appearance, and not usually as an adulteration. The most remarkable instance is that of a silken thread with fine woollen fibre wound round it, the object of this plaiting being to make a very slender, but yet strong, filament, apparently of wool.

NOTES.

Microscope Stands.

Page 2.—In the *Monthly Microscopical Journal*, vol. iii., p. 183, Dr. Carpenter gives an account of the "Comparative Steadiness of the 'Ross' and 'Jackson' Microscope Stands." The result of his experience under very trying circumstances is decidedly in favour of the latter mode of construction.

Immersion Objectives.

Page 18.—Object-glasses are now made in which the corrections are adapted for viewing an object through water, instead of air as in the usual construction ; the advantages are increase of light and improved definition. The drop of water is held by capillary attraction between the front lens and the cover-glass. This system of construction is, of course, only applicable to glasses of short focal length, as the $\frac{1}{8}$th and above. Foreign makers adapt these objectives for use only as immersion lenses. The English opticians have constructed theirs so as to be capable of use either through air or water, by means of an additional front combination, which can be substituted at pleasure for the ordinary one ; this plan is a decided advantage, as it gives the power of using the objective in the usual way as well as by immersion.

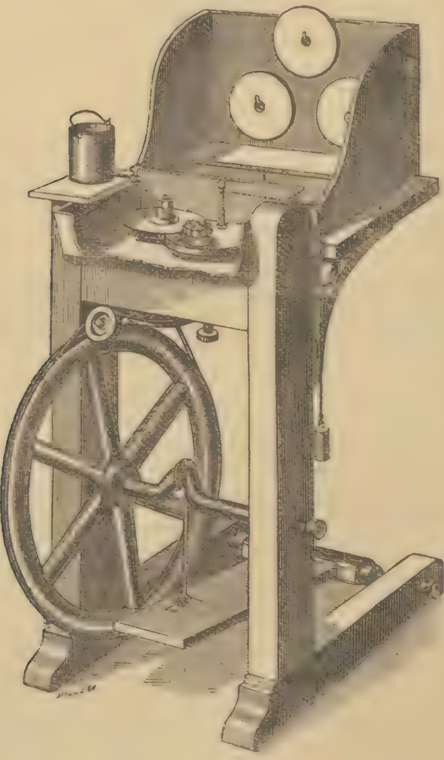
Molecular Motion and Organic Matter in the Air.

Page 30.—Papers on "Molecular Motion," by E. P. Joule, LL.D., F.R.S., will be found in the *Chemical News*, vol. xxi., p. 66, and on "Organic Matter in the Air," by Dr. R. A. Smith, F.R.S., in the same volume, pp. 64, 78.

Cutting Glass.

Page 35.—The crystal represented in Fig. 13 exhibits several cutting edges besides the one marked *a*, *b*. Where large quantities of glass are cut, as in wholesale warehouses, the edge is frequently worn out; the diamond is then re-set, by which one of the other edges is placed in the proper position for cutting.

Fig. 46.



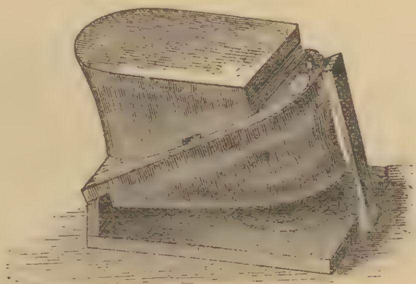
SOLUTION OF CANADA BALSAM IN BENZOL.

Page 64.—The solution of Canada balsam in benzol does not absorb air like pure balsam; care should therefore be taken to prevent any being included in the object; and, as this medium contracts in drying, a sufficient quantity should be used to prevent spaces being left under the cover, as the fluid shrinks.

CUTTING ROCK SECTIONS.

Page 67.—The third volume of Holtzapffel's "Turning and Mechanical Manipulation" is entirely devoted to an account of various abrasive processes, many of which will be found useful to the microscopist who makes petrology his study. The machine for cutting rock sections used by Mr. Jordan is now manufactured by Messrs. Cotton and Johnson, Grafton Street, W.C. It is an extremely compact piece of apparatus (Fig. 46), and much more convenient than the ordinary lapidary mill for microscopical work, as it is provided with means of regulating the thickness of the section, and also of keeping it up close to the slicing-

FIG. 47.



disc by means of a self-acting arrangement; special care is taken to make it more cleanly in work than most grinding and slitting apparatus. The same firm also manufacture a very portable and convenient pair of bellows (Fig. 47), requiring no fixing, and which, used in combination with Herapath's gas blow-pipe, will be found convenient for such processes of glass-working (p. 38) as require a greater heat than can be obtained from the Bunsen burner.

PARABOLIC LIEBERKUHN.

Page 101.—Mr. Collins attaches the parabolic lieberkuhn to a steel rod, provided with suitable adjustments

FIG. 48.

somewhat like those of the stage forceps; this is made to fit into a hole in the stage, or some other convenient part of the stand, and allows the reflector to be used with any object-glass, dispensing with the use of the adapter.

ILLUMINATING OBJECTS BY REFLECTED LIGHT.

Page 104.—There are two other modes of illuminating objects by reflected light with high powers, which are made but little use of, notwithstanding the known advantages of lighting from above. In one, the invention of Mr. Charles Brooke, a small plane speculum or flat lieberkuhn is placed on the setting of the object-glass in the usual manner, its surface being coincident with that of the front lens. This receives the oblique rays from Wenham's parabola, and reflects them downwards on the object, which, for being thus viewed, should be uncovered. —*Brit. Ass. Rep.*, 1851, pt. 2, p. 7. Mr. Wenham uses a small truncated hemispherical lens; this is temporarily attached to the under side of the slide by means of a minute quantity of oil of cassia or other highly refractive fluid. The light of the paraboloid is thus caused to pass through the slide and fall upon the under side of the thin cover-glass, at an angle suitable for total reflection; the object will be found to be brilliantly illuminated if the apparatus is properly managed.—*Monthly Microscopical Journal*, vol. ii., p. 29. This simple contrivance can be used with objectives of the highest power.

Phenomena of Interference.

Page 122.—The phenomena of interference are most readily understood by the aid of a simple and ingenious model designed by Charles Woodward, Esq., F.R.S. It consists of a wooden frame (Pl. 8, fig. 1, F, F1), in which are arranged a number of square wooden rods, the tops of which are cut to the form of a series of waves. They are prevented from falling out by pins, suitably placed, and for convenience of reference the situation of the summits of the waves is marked by stars on the frame, F, F1. A solid block of wood (fig. 2, B, B1), having its upper surface cut to correspond with fig. 1, completes the apparatus. If the frame, F, F1, is placed upon the block, B, B1, so that the *stars* are *coincident*, as in fig. 3, it represents two waves starting together, and, by coalescence, augmenting each others intensity indicated in the model by a wave of double height. But if placed, as in fig. 4, so that the *dots* on B, B1 correspond with the *stars* on F, F1, the tops of the rods will sink into a straight line, illustrating the destruction of wave motion by interference when a wave starts half a wave's length before another.

Plate L

Scale Fig 12 to 14

Scale Fig 1 to 11

Plate II.

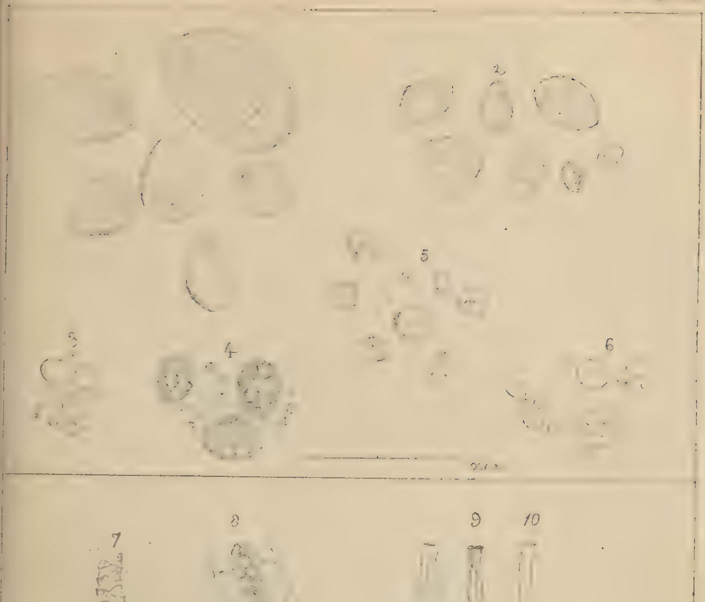


Plate IV

·1 in ——— ·01 in

Scale for Fig. 1

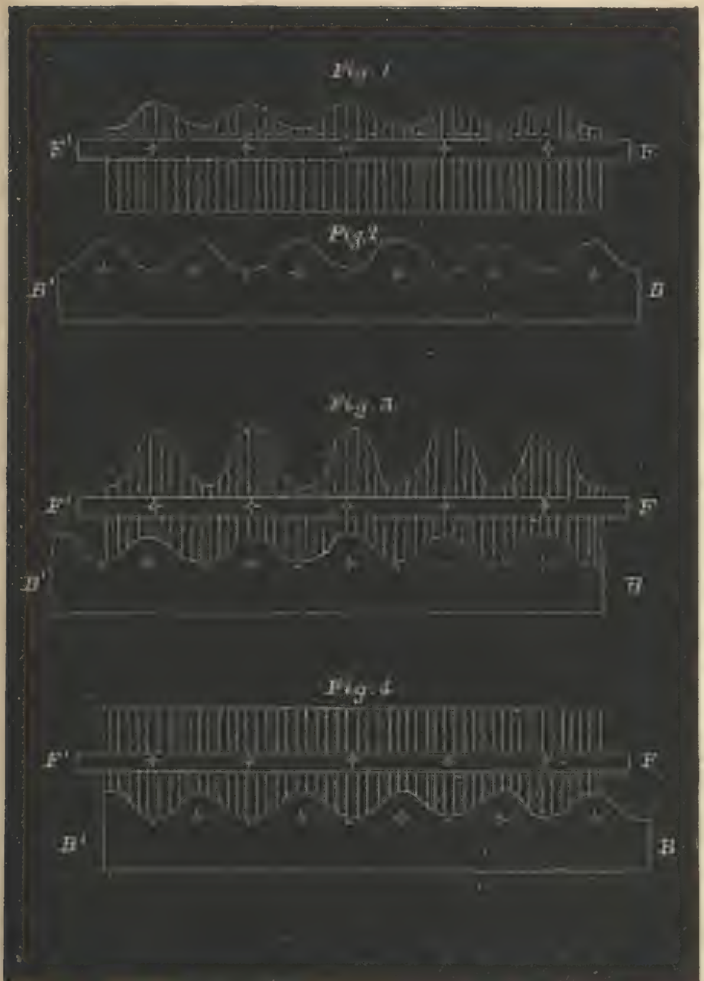
W West imp

Plate V.

.. Nest imp.

1 2 3 4 5

Plate VIII.



W West imp

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ERRATUM.

Page 214, line 8 from top, for "*plaiting*" read "*plating*."

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